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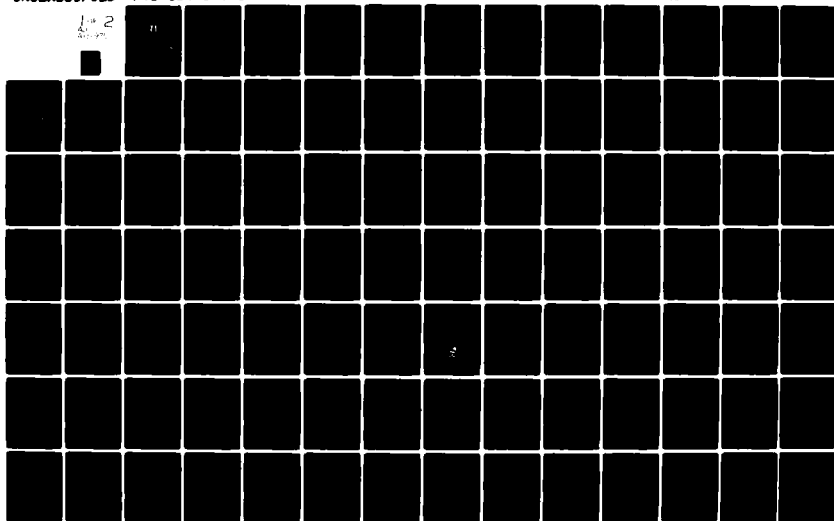
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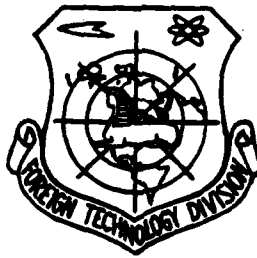
FOREIGN TECHNOLOGY DIVISION



BALLISTIC-MISSILE DEFENSE WEAPONS

by

Liu Shao Ch'in, Li Hsien Lin



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FTD-ID(RS)T-1210-81

11 February 1982

MICROFICHE NR: FTD-82-C-000183

BALLISTIC-MISSILE DEFENSE WEAPONS

By: Liu Shao Ch'in, Li Hsien Lin

English pages: 116

Source: Ballistic-Missile Defense Weapons, Kuo Fang Kung Yeh Publishing
House, pp. 1-100 1981

Country of origin: China

Translated by: SCITRAN

F33657-81-D-0263

Requester: FTD/SDBS

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A WORD FROM THE PUBLISHER

In order to meet the demands of the great number of workers, farmers, soldiers and young people for a better understanding of aeronautical science and technology so that they may better serve Socialism and national defense, and contribute to the realization of our "Four Modernizations," we have, in collaboration with the Aeronautics Editing Department, compiled the "Aeronautics And Space Technology Pocket Book Series."

It is our intention to make these pocket books lively in style, easy to read and understand, and with many helpful illustrations, thus making them suitable for the great majority of the public.

At our present level, deficiencies and errors are apt to be found in the contents of these books. We sincerely hope that the reader will kindly point these out, and also give us valuable suggestions and opinions, thus enabling us to make improvements in popularizing aeronautical science and technology.

PREFACE

It is only natural that the shield coexists with the spear.

The appearance of each offensive weapon necessarily brings about the birth of a countermeasure. Ballistic-Missile Defense (BMD) weapons are weapons designed to fend off nuclear ballistic missiles. These are still being developed and improved upon.

The BMD weapon is a weapon that is massive, complex, involving broad areas of technologies, and very expensive. The United States of America had to spend over \$10 billion over a period of more than 20 years to come up with the "SAFEGUARD" weapon system. However, the system lacked the desired effectiveness, and was cancelled in February 1976.

This book deals systematically with the BMD weapon systems. It consists of ten parts. The first eight parts contain such subjects as the elements, functions, interception process and principles of control and guidance of the BMD weapon system, as well as defense penetration and countermeasures, and the structure and characteristics of Anti-Ballistic Missile (ABM). Part Nine examines some other means for intercepting guided missiles, such as stimulated light weapons and particle beam weapons. In Part Ten, we look at some of the BMD weapons developed abroad, and talk about the trends in BMD weapons development.

Owing to the broadness of the subject and our limited understanding, we are apt to make mistakes here and there. Suggestions and criticisms are most welcome.

The data for the U.S. and Soviet BMD weapon systems used in this book have been taken from foreign published material. As the various sources do not

always agree, these data are to be used for reference only.

Professor Shih Ch'ao Li and Comrade Shen Chung Fang have carefully proof-read the manuscript, and made many valuable suggestions; Comrade Ch'en Ming Ti offered much help in the preparation of this book; and Comrades Chang Po Chih and Lu Ching did the illustrations for the book. To all of the above, we wish to extend our sincere gratitude.

I. SURVEY OF BALLISTIC-MISSILE DEFENSE WEAPON SYSTEMS

During World War II, for the purpose of expanding their invasions, the Germans hired such rocket experts as von Braun to set up a secret base for rocket research and experimentation. They employed 20,000 workers and technical personnel to carry out the project of fabricating rockets. On October 3, 1942, the "V-2" ballistic missile was successfully completed. At that time, it was the newest long-range weapon. In 1944 Germany first started using "V-2," and embarked on attacking London. The missile was launched from a place in the suburbs of the capital of the Netherlands. It flew several hundred kilometers, and landed in downtown London.

In an attempt to defend themselves, the British thought up a system to intercept the guided missile, as shown in Fig. 1-1. However, the idea was later

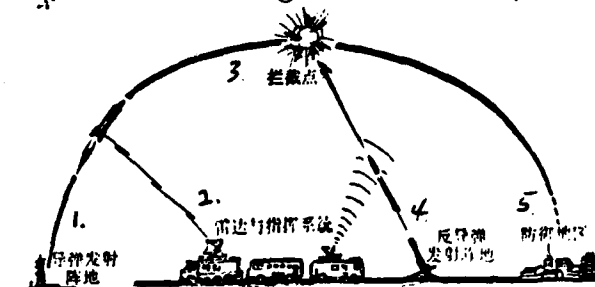


Fig. 1-1. The first ballistic-missile defense system conceived by man.
Key: (1) Missile launching site;
(2) Radar and command system; (3) Point of interception; (4) Anti-missile missile launching site; (5) Defense region.

abandoned because of the complexity of the system and the fact that many of the technical problems were unsolvable at that time. For instance, the radars were unable to locate any target (such as an airplane) beyond 100 km, and the accuracy of the measurements was very poor. To recognize the invading target (the targets referred to in this book will be mainly the invading ballistic missiles), before interception, measure the parameters of its trajectory (such as velocity and position), and then guide the anti-missile missile for interception, one is really

pressed for time. If the target moves at an average speed of 4 km/sec., then only 25 seconds are allowed between detection of the target and its destruction. In order to complete the assignment within such a short time, it is necessary to have an anti-missile missile that flies at a great velocity and that is guided with a fairly high accuracy. Fabrication of such anti-missile missiles and guidance system was technically impossible at that time. Hence, the ballistic-missile defense weapon depicted in Fig. 1-1 became just an illusion.

As time went on, the nuclear guided missile weapons increased in number, range of trajectory and accuracy of hitting the target. This spurred the development of ballistic-missile defense weapons.

In ancient wars, spears and shields were used. The spear was used in offense, to destroy the enemy; the shield was used in defense, to preserve the life of the attacked. In an encounter, usually both were employed. These offensive and defensive roles have continued down to the present. Every country in the world has been engaged in the study of various advanced "spears" and "shields." Rifles, long-range artillery, bombers, guided missiles, and airborne weapons may be considered as today's "spears;" helmets, bomb shelters, anti-aircraft guided missiles, anti-satellite weapons and missile defense weapons may be regarded as today's "shields."

The BMD weapon was evolved in the sixties as a type of defensive weapon. The development has been slow owing to the complexity of the system and other reasons.

What, then, is a BMD weapon?

"BMD weapon" stands for Ballistic-Missile Defense weapon. It is one of the strategic defense weapons, belonging also to the family of air-defense weapons.

(Air defense weapons include anti-aircraft, anti-missile, anti-satellite and anti-airborne weapons.)

The mission of the BMD weapon is to counter the attack of ballistic missiles (mid-range, long-range or intercontinental ballistic missiles) so as to protect certain important places. At the same time, it is used to warn of other invading weapons.

To accomplish this, the BMD weapon system has to be able to detect the offender in time (the target being the invading ballistic missile), correctly identify the target (from among false targets), accurately track it, quickly make a decision, and effectively intercept it. The subsystems corresponding to these five operations are the advance-warning system (searching, acquiring and tracking), the discrimination system (screening and identifying), the surface guidance system (tracking, guiding the anti-missile missile to intercept the target), the command and control system (organizing counterattack, coordinating the various subsystems), and the anti-ballistic missile (ABM) missile (directly destroying the target).

BMD weapon systems have the capabilities and means to destroy invading guided missiles. These include using the ABM missile, the laser weapons, and particle beam weapon to intercept the target. These measures, employed individually or alternately, can effectively prevent enemy invasion and thus eliminate damages due to surprise attacks. This is the final goal a BMD weapon is to achieve.

The following question is apt to be raised in the reader's mind: Is such a weapon system really capable of coping with sudden attacks by ballistic missiles or airborne weapons? If so, how is the interception accomplished?

II. BALLISTIC-MISSILE DEFENSE WEAPON SYSTEMS AND FUNCTIONS

The BMD weapon system is vested with the duty to destroy the invading ballistic missile (mid-range, long-range and intercontinental guided missile) and other invading weapons, so as to protect military zones, important industrial cities and guided missile underground silos. Its advance-warning system has the additional function of partaking in air-defense duties.

In concrete terms, a BMD weapon system has to accomplish the following:

- 1) It is to detect the invading target as early as possible, and calculate the parameters of the trajectory reliably, so as to provide the ABM missile as much warning time as possible.

If the invading aircraft is detected at the time it is taking off, the intercepting airplanes will have more time to get prepared, and more likely succeed in destroying the offense. In the case of the high-speed missiles, one should try even harder to procure sufficient warning time so as to increase the probability of destroying the invading target.

- 2) After the target is acquired, the data obtained from the advance-warning system should be analyzed so as to determine whether it is a guided missile, a satellite, or a false target. The false targets can be let alone, but each and every guided missile or other invading target should be carefully dealt with.

- 3) The system is to command and direct the anti-missile weapon to intercept the invading target, and completely destroy it.

- 4) All commands have to be speedily delivered, and information obtained from

the various sources (including target properties, target trajectory parameters, etc.) must be handled very quickly.

5) The results of the interception have to be examined, and a decision should be made whether or not to undertake another interception.

A BMD weapon system is usually made up of an advance-warning system, a target discrimination system, a surface guidance system, a command and control system, and an ABM missile, as shown in Fig. 2-1.

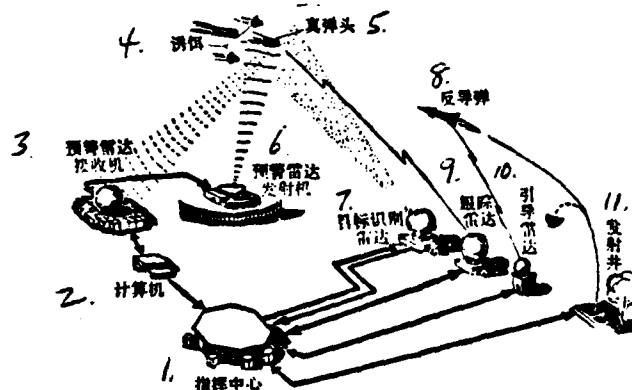


Fig. 2-1. BMD weapon system.
Key: (1) Command center; (2) Computer;
(3) Advance-warning radar receiver;
(4) Decoy material (bait); (5) True warhead; (6) Advance-warning radar transmitter; (7) Target-discriminating radar; (8) ABM missile; (9) Tracking radar; (10) Guide beam radar; (11) Launching silo.

What are the functions of the major parts of the BMD weapon system? Does the system have to be so complicated? Let us first try to understand the functions of each part (subsystem) of the system.

Advance-Warning System

The BMD weapon system has a keen "eye" that keeps watch day and night over the launching area of the enemy's intercontinental guided missile. Even the launching

of missiles ten thousand kilometers away will not be able to escape the "eye" of the system.

The subsystem that contains this "eye" is called the advance-warning system. Hence, the advance-warning system fulfills the first and foremost requirement in the interception process.

The advance-warning system has the responsibility to detect the target, alert the other units, acquire, and track the target. It reconnoiters continually the enemy's activities. Despite the deep skies and thick clouds, it has to be able to detect an attacking missile in flight or being launched (and other invading weapons), estimate the trajectory of the invading missile and its target area, and thus obtain as much time as possible for the BMD weapon to get prepared for war.

The advance-warning system generally includes reconnaissance satellite, sub-horizon radar and long-range searching and tracking radar.

There are usually many stations (tracking stations or observation posts) scattered everywhere in the country, forming a network. Hence, the advance-warning system is also referred to as the advance-warning network.

How does the advance-warning system detect the invading target? We will address this problem in Part VII.

Discrimination System

"One day, the advance-warning system suddenly picked up signals indicating that the enemy's guided missiles was invading. As a consequence, all the guided missiles, BMD weapons, and airplanes got ready for retaliation. A seemingly inevitable war was imminent. Many people were horrified and tried desperately to find a place to hide themselves."

This incident happened in the United States several years ago. The confusion was caused by a problem in the advance-warning system which mistook polar lights for an invading warhead.

From this, one sees that besides being able to detect the targets, the advance-warning system also has to be able to screen them.

Usually, to aid penetration, the offense employs false targets (also called baits, such as balloons, metal threads and metal foils) to confuse the advance-warning system (Fig. 2-2). Under these conditions, it is essential for the advance-warning system to be able to screen and sort the targets.

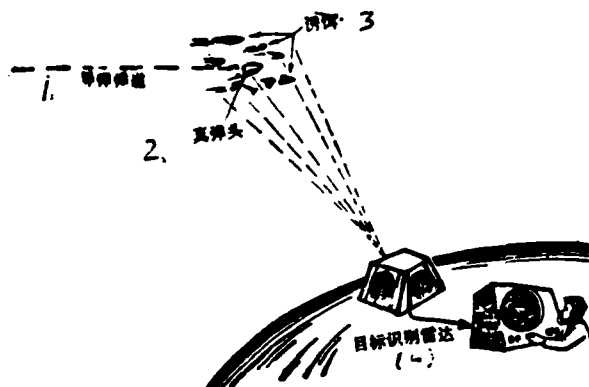


Fig. 2-2. The "enemy" hiding among false targets.
Key: (1) Missile trajectory; (2) True warhead; (3) Bait; (4) Target discriminating radar.

Discrimination means to recognize the missile warhead from among the false targets. The subsystem responsible for this job is called the target discrimination system.

Discrimination can be achieved using individual discriminating equipment such as radars or optical systems; it can also be carried out by means of the tracking radar.

To correctly identify the target, the discriminating equipment must possess a high resolving power, and not mistake polar lights or man-made satellites for invading warheads, or vice versa.

There are many methods for discrimination. We will discuss two commonly employed methods in Part VIII.

Surface Guidance System

Everybody knows that one needs to aim while shooting, making use of the gun-sights.

The system guiding the ABM missile toward the target is called the guidance system. The function of the guidance system is equivalent to that of the gun-sights. As the system is fairly complicated, and is usually set up on the surface of the earth or underground, it is also referred to as the surface guidance system.

The main duty of the surface guidance system in a BMD weapon system is to track the target and guide the ABM missile toward the target and intercept it. Thus it is a fast and accurate system consisting of surface launching facilities, target tracking radar and ABM missile guide beam radar.

The sequence of operations is as follows: Based on target information provided by the advance-warning system, the target tracking radar continually determines such trajectory parameters as the precise position and velocity of the target. This information is immediately transferred to the command and control system and the surface guidance system which accordingly command the launching of the ABM missile. The high-speed computer takes in values for the relative position and velocity of the ABM missile and the target, formulates control commands and transmits them to the autopilot. In this manner, the ABM missile is accurately

controlled and guided toward the target for interception. In short, the operation consists of tracking the target, launching the ABM missile and guiding it to intercept the target.

The main function of the ABM missile guide beam radar (i.e. surface guide beam radar) is to guide the ABM missile accurately toward the target. It tracks the specified target making use of the target trajectory data provided by the target tracking radar. At the same time, it guides the high-altitude or low-altitude ABM missile to accomplish the mission of interception. In the case of low-altitude interception, the accurate data of the target have to be obtained about 20 seconds in advance. (At this time, the distance between the guidance radar station and the target is about 100 km.)

ABM Missile - the Interceptor of the Weapon System

The Anti-Ballistic Missile (ABM) missile is the interceptor in the BMD weapon system, and is one of the means for destroying the oncoming target. (Other methods of destruction will be covered in Part IV.) It is like the cannon ball of an anti-aircraft artillery system, directly encountering and damaging the target. ABM missiles are generally classified as high-altitude or low-altitude ABM missiles, intercepting high-altitude and low-altitude targets respectively. The former are called high-altitude interceptors while the latter are called low-altitude interceptors. High-altitude interceptors are to destroy targets (true and false targets alike) higher than 100 km above ground level and protect the entire defense region. (The defense region includes such protected regions as military establishments, important cities, industrial centers and intercontinental guided missile bases.) They constitute the first defense line of the BMD weapon system. "SPARTAN" (U.S.) and "RUBBER BOOT" (Soviet) are two examples of high-

altitude interceptors. ("SPARTAN" intercepts in the region between 160 and 480 km in altitude.)

Low-altitude interceptors are to intercept all the targets that have penetrated the first defense line and are flying at lower altitudes. The low-altitude interceptors make up the second and most important defense line. "SPRINT" (U.S.) is an example of low-altitude interceptor. (It intercepts in the region between 32 and 48 km in altitude.)

What are the high-altitude and low-altitude interceptors like? What are their structures? We will answer these questions in Part V.

Command And Control System

Since the beginning of military history, command and control have played a major role in wars.

The command and control system is to the BMD weapon as the brains are to a human being. It commands and controls the operations of the various parts of the weapon system so that they function as one whole unit, a powerful weapon for destroying the invading target.

In case the advance-warning system has detected an attacking target and the discrimination system has confirmed it, the command and control system must decide quickly and accurately on a counterattack policy. The command personnel will, via the command and control system, order the launching of the ABM missile (first the high-altitude interceptor, then the low-altitude interceptor). Based on target information (trajectory data), the surface guidance system will continually modify the trajectory of the ABM missile and guides it towards the target with great accuracy.

With today's advanced and modernized weapons, the attacking speed and wrecking ability of these weapons have forced both sides of the combat to make decisions and react quickly. Thus it is necessary that the command and control system of the BMD weapon possess such characteristics as high reliability, high speed, great accuracy, flexibility and ability to survive an attack.

The command and control system is usually comprised of command (command center), communications (communications link) and data processing.

The command center is at the head of the BMD weapon system. It is a decision-making organization responsible for routing all the commands and messages, and commanding and assigning work to the various subsystems.

Messengers carrying messages on horses that one often sees in movie scenes is a common means of communication in times of old.

Communication is the nervous system of the BMD weapon system that transmits messages from one subsystem to another. All messages are swiftly transmitted and exchanged by way of the communications stations which assure that the signals flow smoothly among the subsystems.

The requirements of communications are speed, accuracy, reliability and security. It is a completely automated system. The following incident serves to illustrate the importance of security and reliability. On April 18, 1943 the code used by the Japanese highest military commander to specify the operations was deciphered by the American intelligence. As a result, the U.S. Air Force was able to intercept and destroy on the spot the airplane that the Japanese admiral Isoroku Yamamoto was riding in. This was a remarkably successful air combat during World War II.

In data processing, the various results of measurement are manipulated to obtain useful information. All the data obtained during the time between target detection and target destruction are speedily processed (e.g. smoothing of data) so as to calculate the position and velocity of each and every target. The targets are then sorted and arranged in the order that they should be destroyed.

The purpose of data processing is to assure the reliability of the target signal obtained by the radar. The data measured by the radar usually contain various types of errors. Therefore it is necessary to use mathematical methods to manipulate them and get rid of the errors in measurement. For example, application of smoothing or mathematical filtering methods to the measured data can eliminate errors due to the measuring process and thus increase the reliability of the data.

The tool for data processing is the electronic computer, with its characteristic high speed and large capacity. No mistakes can be tolerated. A breakdown of the computer or a miscalculation can bring great disasters. For this reason, the data processing system has a built-in automatic testing and debugging function to remove the possibility of a breakdown and assure the reliability of the calculated results.

The above is a brief account of the functions of the major subsystems of a BMD weapon system.

III. INTERCEPTION PROCESS OF THE ABM MISSILE

If we say that the intercontinental guided missile is a modern, advanced weapon made up of thousands of elements, then even moreso is the BMD weapon system.

In order for such a complicated system to accomplish the mission of destroying the invading ballistic guided missile, all four functions of advance-warning, discrimination, tracking and interception have to be successfully executed. These four functions when well coordinated under the same command system will be sure to intercept and destroy the invading target.

A Brief Introduction to the Interception Process

How does the ABM missile destroy invading targets?

Advance Warning The advance-warning system is responsible for keeping constant vigilance (through the use of reconnaissance satellites and sub-horizon radars, etc.). It reconnoiters, searches and keeps watch over enemy guided missiles (guided missiles launched from underground silos, from aircraft, or from submarines).

As soon as the reconnaissance satellite or sub-horizon radar detects an invading target, the advance-warning system sends out alarms. The long-range tracking radar immediately starts acquiring and tracking the target, calculates the approximate trajectory and landing site of the target, and estimates the extent and area of possible damage. If the invading warhead is expected to land within the defended region, the warning radar will give the target trajectory parameters to the air-defense command center and thus complete the duty of advance-warning.

Discrimination Based on the target information provided by the advance-warning system, the discrimination system tracks the target. Information of the true targets (such as target shape and trajectory parameters) is analyzed to yield target characters and to sort out the different targets. False targets like man-made satellites, meteorites and polar lights are rejected, and the invading warheads identified. The discrimination system then calculates the number of the invading targets and their trajectories, puts the true targets (warheads) in the proper order, and reports to the command center.

Tracking The long-range precision tracking radar follows the target closely, accurately determines the target trajectory, and processes data obtained from measurements on target distance, azimuth angle, slant angle and rate of change of distance (velocity) so as to eliminate errors of measurement (generally termed "noise" in the language of engineering). It will then be able to estimate the landing site of the warhead.

Interception After the command center has studied the various information inputs, and decided that the invading target will fall in the defense region, it will immediately order all personnel and subsystems in the entire defense region to get ready for combat.

The command center distributes firepower according to the target information provided by the radars. The high-altitude interceptor will first be placed in combat. After receiving the order, the high-altitude interception team gets ready for launching. The interceptor is oriented so that its trajectory will pass through the chosen target.

After the launch command is given, the high-altitude interceptor is launched at once. The flight control system of the interceptor (including the guidance

system and altitude stabilization system) controls the interceptor so it flies toward the chosen target. The actual position and velocity of flight at each moment is taken into account to modify the trajectory of the interceptor so that the interceptor will be brought close to the target. When the target is within the range of the destructive force of the war section of the interceptor, the warhead detonates and destroys the target.

The outcome of the interception process is analyzed by the command and control system. In case some of the targets have not been destroyed and continue to fly towards the defense region, when these enter the atmosphere (at an altitude of about 80 km), the target tracking radar will once again engage in tracking and discrimination. The fact that the lighter decoy material like metal foils and strips are generally either burned up in the atmosphere or lag behind the warhead (light baits are only effective outside the atmosphere) sets up a criterion for discrimination. Some of the heavier decoy material that have succeeded in penetrating through the atmosphere will, because of atmospheric drag, also lag behind the warhead. Hence, the target discriminating radar can readily screen the decoy material from the true target. In accordance with the direction of entry of the target, the command and control system once again distributes the firepower, and orders the launching of the low-altitude interceptor. The surface guidance system follows definite guidance rules to guide the anti-missile missile towards the target to destroy it. This is briefly how the process of interception is accomplished.

Fig. 3-1 shows the process of interception.

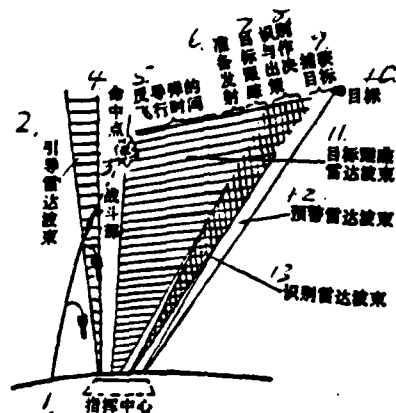


Fig. 3-1. Schematic diagram of the interception process.

Key: (1) Command center; (2) Beam of guide beam radar; (3) Warhead section; (4) Hit point; (5) ABM missile time of flight; (6) Getting ready for launching; (7) Target tracking; (8) Discrimination and decision-making; (9) Target acquisition; (10) Target; (11) Beam of tracking radar; (12) Beam of discriminating radar; (13) Interference zone

Time Allocation

We will illustrate the interception process using as an example an invading intercontinental guided missile with a range of 10,000 km.

The total time of flight of the invading intercontinental guided missile will be around 33 minutes. The allocation of time among the various operations of the BMD weapon system will be approximately as follows:

1) 26 minutes -- Advance-warning system detects the invading target and gives 26 minutes warning time (i.e. the amount of time between the time the target is detected and the time the target will land on the ground). The BMD troops get ready for combat.

2) 17-23 minutes - Target-tracking radar tracks the target. The target trajectory is calculated and the hit point and target landing point are estimated.

3) 7 minutes - Target-discriminating system screens and sorts targets. The trajectory and intended hit point is calculated for the true target. (It is difficult to know the actual hit point. One can only calculate the hit point based on the data measured by the radars. We call this the intended hit point). At this time, the target distance (i.e. the distance between the target and the center of the defense region) is about 3,000 km.

4) 3 minutes - The system gets ready for counterattack. The high-altitude interceptor is oriented to aim at the intended hit point. The command and control system gives orders, and the high-altitude interceptor is launched. At this point, the target distance is about 1,300 km.

5) 90 seconds - Target is intercepted. The surface guidance system guides the high-altitude interceptor towards the target. Now the target distance is about 700 km.

6) 60 seconds - The warhead section of the high-altitude interceptor detonates and the target is destroyed. At this time, the target distance is about 450 km.

7) 30 seconds - Discrimination process is repeated. The BMD system evaluates the outcome of the interception process. If the targets have all been destroyed, then the system prepares itself for the next combat. If the targets have not been destroyed, then the target discriminating system utilizes the method of atmospheric filtering to sort the targets that have entered the atmosphere. The warhead is then tracked, and the target trajectory and intended hit point are

calculated. The low-altitude interceptor gets ready to go. Target distance is now approximately 200 km.

8) 20 seconds - Targets are again intercepted. The low-altitude interceptor is launched as commanded by the command and control system. The surface guidance system guides the low-altitude interceptor towards the target. Target distance is 100 km, approximately.

9) 13 seconds - Target destruction is again carried out. When the target comes within the destruction range of the warhead, the warhead is detonated to destroy the invading target. At this point, the target distance is approximately 50 km, and the target is about 15-20 km above the groundlevel.

The above is a brief account of the different stages of interception of invading targets by the BMD weapon and how the combat time is roughly divided among the different stages.

6 Minutes And 6.5 Seconds

In the following, we will use the high-altitude interceptor "SPARTAN" and the low-altitude "SPRINT" of the U.S. "SAFEGUARD" system as examples to illustrate the combat process of a BMD weapon system.

Let us first examine the six minutes of time of flight of the "SPARTAN."

Before launching, the high-altitude interceptor "SPARTAN" is stored in a rectangular steel-reinforced concrete underground silos, 2.7 m in length and width and 21.9 m deep.

The advance-warning satellite keeps watch over the enemy's launching area. It sounds the alarms as soon as it detects the launching of the invading guided

missile, and the BMD system makes pre-combat preparations. The perimeter acquisition radar discovers the invading target when it is about 4,300 km away and thus provides 10 minutes warning time. When the target is about 3,360 km away (eight minutes before the warhead will hit the ground), orders are given to launch the ABM missile. The "SPARTAN" is ignited, and when the thrust exceeds 204 tons, it is lifted off vertically, gradually tilting as it gains altitude. When the target is 1,280 km away (two minutes), the target tracking radar (missile site radar) starts to track the target. After about four to five seconds of flight, the "SPARTAN" drops its first stage, and the main engine of the second stage starts functioning. After 60-65 seconds, the "SPARTAN" has completed its reorientation and has gained sufficient speed (approximately 2.2 km/sec.). The main engine of the second stage is turned off and the third stage is separated from the second stage. The "SPARTAN" is now in free flight outside the atmosphere. The main engine of the third stage is turned on or off in accordance with the position and velocity of the target so that the ABM missile is flying dynamically and aimed accurately at the target. Once the target gets within the destruction range of the "SPARTAN," the ground-based guidance system sends out the command, and the warhead explodes, emitting strong X-rays to destroy the target. The altitude at which the "SPARTAN" intercepts the target is approximately 650 km. The interception takes place about 90 seconds before the target is expected to land.

The entire combat time is approximately six minutes for the "SPARTAN," and the process of the combat is shown in Fig. 3-2.

Let us now look at the 6.5 seconds of flight of the low-altitude interceptor "SPRINT."

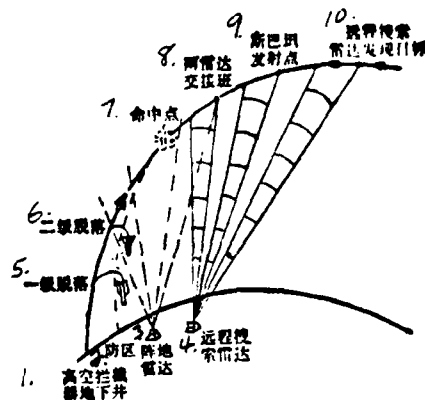


Fig. 3-2. Schematic diagram of the combat process of the "SPARTAN."

Key: (1) Underground silo for the high-altitude interceptor; (2) Defense region; (3) Site radar; (4) Perimeter acquisition radar; (5) The first stage separates; (6) The second stage separates; (7) Hit point; (8) The two radars shift duties; (9) The "SPARTAN" is launched at this moment; (10) Perimeter acquisition radar detects the target.

Before launching, the "SPRINT" is stored in the underground silo. When the target is about 100 km away from the defense region (20 seconds before the target is expected to land), orders are issued to launch the "SPRINT." The igniter is activated, and the high-pressure gas jet pushes the "SPRINT" off ground. The booster rocket is then ignited. After approximately two seconds of flight, the first stage separates, and the main engine of the second stage is started. Based on the target parameters of the target and the "SPRINT," the computer formulates control commands to modify the trajectory of the "SPRINT." When the target comes within the destruction range of the "SPRINT" (at this point, the target is about 5.2 km in altitude and is about 13.5 seconds away from landing), command is given, the nuclear warhead explodes and destroys the target.

The interception process of the "SPRINT" takes about 6.5 seconds, and is as shown in Fig. 3-3.

IV. PRINCIPLES OF CONTROL AND GUIDANCE

In intercepting the invading target, the BMD weapon should choose the best course of attack.

In general, a moving target is more difficult to hit than a stationary target, as is the case with shooting rifles.

Because of the high speed of invading missiles (the speed of intercontinental guided missiles being about 7 km/sec., approximately 20 times the speed of sound) and the short time for interception (the entire interception process lasting only a few seconds to a few minutes), it is much harder to intercept these than other aircraft that fly at slower speeds.

There are two sides to everything. There are difficulties involved in the interception of high speed warheads; nevertheless there are also advantages. The advantages lie in the fact that the warhead flies along a definite trajectory which can be accurately determined mathematically from information obtained by the radars, such as target distance, azimuth angle, angle of inclination and rate of change of distance (velocity).

By taking advantage of the helpful conditions, one can find the best way of interruption and choose a good course for interception.

Course of Interception

The course of interception of the ABM missile can be various. However, as the unmotorized (without propelling equipment or control system) warhead follows a definite trajectory. The course of interception cannot be chosen at random, but generally falls into the following two categories:

1) Meet and attack. The ABM missile intercepts the target by meeting it face to face, as shown in Fig. 4-1.

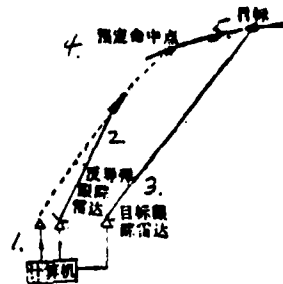


Fig. 4-1. "Meet and attack" schematic diagram.
Key: (1) Computer; (2) Tracking radar of the ABM missile; (3) Target tracking radar; (4) Intended hit point; (5) Target.

2) Chase and attack. The ABM missile intercepts the target by chasing it from behind (see Fig. 4-2).

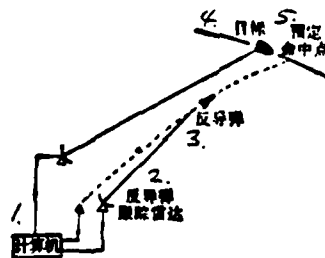


Fig. 4-2. "Chase and attack" schematic diagram.
Key: (1) Computer; (2) Tracking radar of the ABM missile; (3) ABM missile; (4) Target; (5) Intended hit point.

Of these two, the "Meet and attack" scheme is usually adopted.

How is the course of interception determined for this manner of attack?

The guidelines are to use the least amount of time and energy (propellant) and to effectively destroy the target. But how does one go about doing it?

The target tracking radar and the surface guidance radar separately measure the trajectory parameters of the target and those of the ABM missile. The trajectory of the target and the intended hit point are mathematically determined. If

the ABM missile faithfully flies toward the intended hit point, it will hit the target. The course of interception is thus determined.

One may wonder why the ABM missile is aimed at the intended hit point rather than the target.

The answer becomes obvious when one looks at the way an experienced old hunter goes about hunting hares. The old hunter always aims ahead of the hare. This is because it takes some time for aiming, and during this time the hare will have moved a distance forward, just in time to meet the bullet. If he had aimed directly at the hare, then the bullet would certainly hit a point behind the hare.

Target interception by ABM missiles employs the same principle as that used by the old hunter. As both the target and the ABM missile are high-velocity flying bodies, if the course of interception is taken as the line connecting the target and the ABM missile, the result will be a sure failure. This is because when the ABM missile reaches a certain instantaneous position of the target, the target will have flown to another position at the approximate speed of 7 km/sec (speaking of intercontinental guided missiles). Hence, the ABM missile should be guided to fly toward the intended hit point, just as the old hunter would aim ahead of the hare.

The path along which the ABM missile flies toward the target (note that this is not the straight line connecting the two) is termed the reference trajectory. When the soldiers form lines, they refer to the position and orientation of the "reference-soldier" to adjust their own position and orientation. What is the reference used in deciding whether the ABM missile has the correct instantaneous position and direction of flight? It is the reference trajectory which has been determined from the characteristics of the motion of the target and the capability of the dynamic flight of the ABM missile (see Fig. 4-3). Once the reference

trajectory is determined, the position and direction of flight of the ABM missile can be specified.

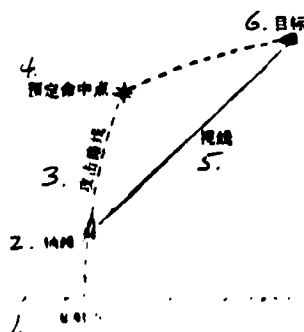


Fig. 4-3. Schematic diagram of course of interception.

Key: (1) Launch point; (2) Axis; (3) Course of attack; (4) Intended hit point; (5) Line of sight; (6) Target.

The scheme of controlling the ABM missile so that it follows the reference trajectory is termed the guidance rule. Hence, we may say that the problem is to design a reference trajectory, i.e. to find the best guidance rule and guide the ABM missile accurately toward the target. The trajectory for guiding the ABM missile to chase and attack is as shown in Fig. 4-4.

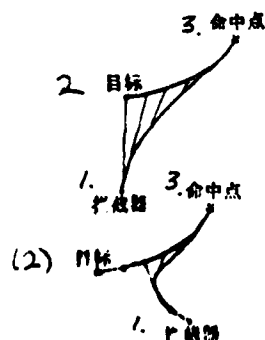


Fig. 4-4. Trajectory for "chase and attack" guidance.

Key: (1) Interceptor; (2) Target; (3) Hit point

In the actual flight of the ABM missile, certain factors (such as errors in measurement, some inaccuracy in the building of the ABM missiles) may cause the actual path of the ABM missile to deviate from the reference trajectory and not

fly toward the hit point, thus missing the target altogether. This is one of the possible reasons for not destroying the invading target.

Another cause for failure to destroy the target is a substantial error in the target trajectory data measured by the radar. The intended hit point calculated from such inaccurate data will thus "drift away" (i.e. deviate from the actual hit point) and result in the ABM missile missing the target.

For this reason, the surface guidance system takes into account the drift of the intended hit point and gives command to bring the ABM missile back to the reference trajectory. Thus, the ABM missile is kept on the reference trajectory and flies towards the target at a high speed and accomplishes the mission of destroying it. (See Fig. 4-5.)

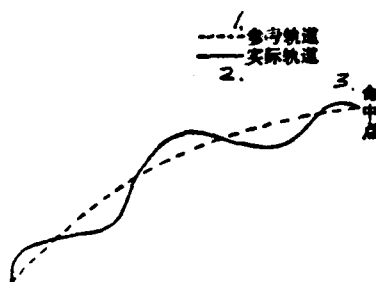


Fig. 4-5. Deviation of trajectory
Key: (1) Reference trajectory; (2)
Actual trajectory; (3) Hit point.

The system that guides the ABM missile along the reference trajectory is the guidance system of the BMD system. It is part of the flight control system of the ABM missile. The guidance system guides the ABM missile according to the guidance rule, i.e. it continually issues control commands to make the ABM missile fly accurately to the intended hit point and intercept the invading target.

In concrete terms, the fundamental duty of the guidance system is to determine the position and velocity of the ABM missile and, based on the target trajectory, give various commands to adjust the trajectory of the ABM missile so that the

ABM missile may successfully intercept the target. The guidance system consists of various equipment that ensure the guidance of the ABM missile towards the target. The major ones are:

- 1) Measurement equipment - It's used in measuring the actual trajectory of the ABM missile, such as measuring the speed of flight and altitude of the ABM missile.

- 2) Missile-carried computer - It calculates at all times the difference between the actual and reference trajectories, and formulates control commands to actuate the control equipment of the ABM missile that carry out these commands. The main requirement for the missile-carried computer are small volume, light weight, low power consumption, high reliability and good capability. The missile-carried computer is capable of directly receiving the control commands sent out by the surface guidance system and converting them to control commands for keeping the ABM missile on the desired trajectory. Missile-carried computers (especially after the appearance of microcomputers) are now widely used in flight control systems, and have become an important constituent of the control system.

- 3) Receiver on the missile - It receives the trajectory data measured by the receiving radar and the various control commands sent out from ground.

- 4) Control equipment - It moves the control elements according to the commands issued from the computer. Movement of the control elements (such as jetavator, gimbaled engines, etc.) can regulate (control) the magnitude and direction of the thrust of the engine, and hence change the speed and direction of the ABM missile so that it flies along the desired path. Thus the ABM missile is brought back to the reference trajectory.

During the flight of the ABM missile, the control system has to determine the thrust vector (magnitude and direction) from the commands issued from the guidance system. The control of the thrust vector is carried out based on the angular error sensed by the autopilot. When the ABM missile is outside the atmosphere, the small nozzles or the gimbaled engine is reoriented according to the strength of the signal of angular error, and thus enables the ABM missile to attain the desired altitude. (See Fig. 4-6, 4-7.)

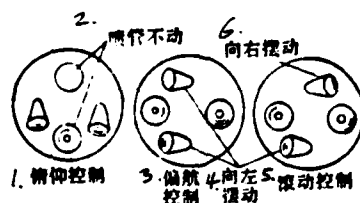


Fig. 4-6. Controlling the motion of the ABM missile using gimbaled nozzles.
Key: (1) Tilt control; (2) Nozzles do not move; (3) Deviation control; (4) Turn to the left; (5) Roll control; (6) Turn to the right.

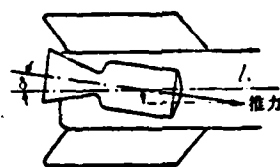


Fig. 4-7. Gimbaled engine.
Key: (1) Thrust.

Hence, the flight control system of the ABM missile contains, besides the guidance system, the flight stabilization system (altitude stabilization system). The flight stabilization system is to ensure good stability of the ABM missile, i.e. that the ABM missile will fly in a stable condition under all possible disturbances (not roll or tumble out of control) and swiftly readjust the altitude via the altitude-control engine in accordance with the control commands. The ABM missile will thus be able to move along the reference trajectory with the required altitude until it destroys the target.

Principles of Guidance

Before we go into the principles of guidance of the ABM missile, let us first look at a tragedy that happened because a passenger plane lost its way.

On April 20, 1978, an airplane carrying 97 passengers took off from Paris, France, and started one of the regular flights of Flight No. 902 to Seoul, Korea. The traveling distance was 13,500 km.

At first everything went smoothly. However, when the airplane was flying over Canada's North Pole front line base, Ellesmere, it mysteriously made a big turn and left the right course. It headed toward the Kola Peninsula in the northern part of the Soviet Union (see Appended Figure) when it was only about four hours away from Paris.

After about two hours of flight, the plane entered the Soviet aerial domain via Murmans.

At this moment, the headquarters of the Soviet Air Force gave orders: "Attention! An enemy plane is invading,"

Upon this, six supersonic Soviet-15 fighters took flight at once and approached the airplane to intercept it.

"Fire!" went the order.

"Whiz! Whiz!" One of the fighters launched two "air-to-air" guided missiles, one of which hit the airplane. A piece of the wing tip broke off, and pieces of the exploded missile hit the body of the plane, killing two persons and wounding 13.

The wounded airplane descended quickly and searched for an emergency landing site.

"The invading airplane has been shot down!" reported the Soviet Air Force pilot to the headquarters after losing the target (the wounded airplane).

It was already dark then. The airplane with the frightened passengers had to land on a frozen lake in the darkness of the night.

The above is a brief account of how the Boeing 707-320C airplane lost its way, entered the Soviet aerial domain by mistake, and was nearly destroyed by the Soviet Air Force.

Why did this passenger plane lose its way? One of the reasons was that the guidance system went out of order and was unable to guide the airplane on the right course.

It should not be hard to image what disasters would result if this kind of problem occurred in an autopiloted aircraft or an ABM missile.

What is the method adopted in guiding an ABM missile?

The method adopted in guiding an ABM missile to intercept targets is usually that of radio command guidance. Command guidance is a guidance system wherein the command controlling the motion of the ABM missile is transmitted to the missile from the surface guidance system, causing it to fly according to the guidance rule.

The requirements on command guidance are that the guidance system be highly accurate and immune to interference, and that the equipments on the missile be reliable. Command guidance is accomplished through the surface guidance system and the equipments on the missile. The command is transmitted via the surface guide beam radar. Fig. 4-8 is a schematic diagram of the general principles of command guidance.

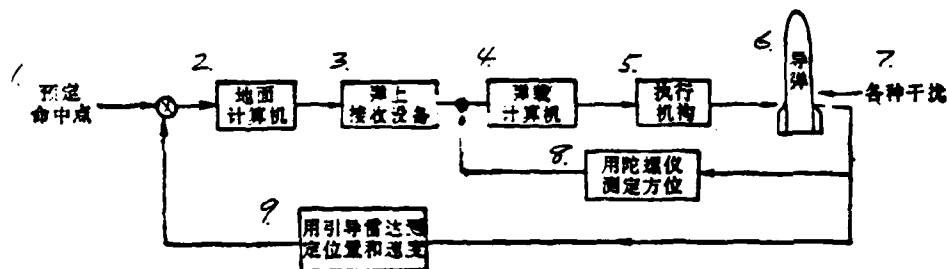


Fig. 4-8. Schematic diagram of the general principles of command guidance.

Key: (1) Intended hit point; (2) Ground computer; (3) Receiving equipment on the missile; (4) Missile-carried computer; (5) Executive organization; (6) Guided missile; (7) Various interferences; (8) Using a gyro-compass to determine azimuth; (9) Using guide beam radar to determine position and velocity.

When the ABM missile is disturbed by external interference, the surface guidance system can calculate the variation in the trajectory data (position and velocity) of the ABM missile from the data measured by the radars. It then performs calculations and comparisons, formulates commands to control the motion of the ABM missile, and transmits these commands to the ABM missile to enable it to accurately intercept the target.

The command guidance is accomplished through the following:

- 1) Surface guide beam radar -- It can accurately measure the position and velocity of the ABM missile and transmit the information to the computer.
- 2) Ground-based computer -- It is made up of one or several macrocomputers. It can perform speedy and accurate calculations on the data obtained by the radars for the trajectories of the target and the ABM missile, compare the results with the intended hit point, formulate control commands, and transmit the intelligence to the guidance system of the ABM missile in secret code.
- 3) Autopilot -- It receives the control commands transmitted from the surface guidance system and compares them with the data obtained by the azimuth measuring

device. It activates the control elements to control the thrust direction of the ABM missile so as to modify the trajectory of the ABM missile.

Command guidance can take one of the following forms: radio command guidance, radar beam-rider guidance and two-radar-tracking-station guidance.

We will use radio command guidance as an example to discuss the characteristics and principles of command guidance. (Radio command guidance is also termed radio line-of-sight guidance.)

While employing radio command guidance, the axis of the line of sight should directly point to the desired azimuth, i.e. to the intended hit point. As both the target and the ABM missile are in motion, only if the axis of the line of sight is at all times pointing to the intended hit point will one be able to hit the target. (See Fig. 4-3.) Obviously, when the ABM missile meets the target, the line of sight is pointing at the target.

The command guidance operates on the following principles.

After the ABM missile is launched, the surface guide beam radar acquires it (i.e. the ABM missile is inside the radar beam). The trajectories of the target and the ABM missile are calculated from the data obtained by the radar, and control commands are formulated in the surface guidance station (or by the missile-carried computer) and transmitted to the control system of the ABM missile in secret code, so that the missile stays within the beam. The deviation of the ABM missile from the line of sight (angular deviation or difference in distance) is the error signal of the system (Fig. 4-9). Hence, with this kind of guidance, the guide beam radar does not track the actual location of the ABM missile, but establishes a line of sight. When the ABM missile is caught up with

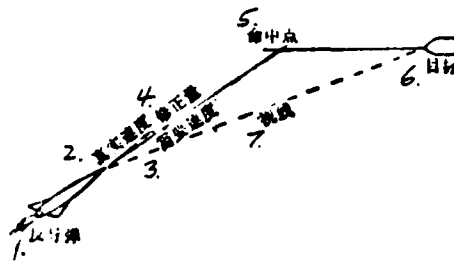


Fig. 4-9. Command guidance.
Key: (1) ABM missile; (2) Actual velocity; (3) Desired velocity; (4) Correction; (5) Hit point; (6) Target; (7) Line of sight.

the guide beam radar, the deviation of the ABM missile from the axis of the radar antenna should be measured, so that control commands may be formulated accordingly to guide the ABM missile to hit the target.

Radio command guidance may be employed during the entire flight of the ABM missile, only during the last stage, or during the initial stage only and then followed by self-homing guidance. If both types of guidance are employed, one has a compound guidance system. The accuracy of guidance of a compound guidance system is in general much higher than that of a simple guidance system.

In command guidance systems, the rules of motion of the ABM missile is generally specified by the surface guidance station. (Of course, these could also be determined by guidance stations situated in the air or on battleships.)

V. STRUCTURES AND CHARACTERISTICS OF THE ABM MISSILE

Regular weapons such as guns and artillery are generally commonly seen. The weapon for intercepting ballistic guided missiles - the ABM missile, however, is not readily available for viewing. How does the ABM missile look? What characteristics does it possess?

During the Spring Festival, kids always love to play with rocket fireworks. Rocket fireworks light up the night one after another. Even though these are only toys, they can nevertheless help us understand the structures of the ABM missile.

The ABM missile is one kind of guided missile that looks roughly like the rocket fireworks. It is also a solid-propellant rocket.

General Structures

The ABM missile consists of a warhead section, a propulsion system, a flight control system and a body. (See Fig. 5-1.)

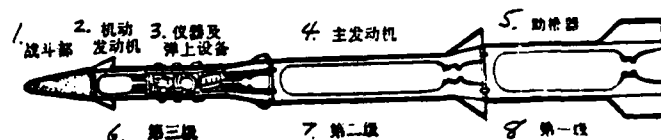


Fig. 5-1. Schematic diagram of the structures of the ABM missile.

Key: (1) Warhead section; (2) Mobile engine;
(3) Instruments and other missile-carried equipment;
(4) Main engine; (5) Booster rocket; (6) Third stage;
(7) Second stage; (8) First stage.

The following can be said about the various parts of the ABM missile. Without the thrust provided by the propulsion system, the ABM missile could not be lifted into the air; without the flight control system, the missile would not be able to fly along a given path or fly toward the hit point to meet the target; without the warhead, even if the missile meets the target, it would not be able to destroy the target. Is it then sufficient to have just these parts? No. A

body is needed to connect the different parts to form a complete unit. The warhead section is like the hand grenade or the bomb; it is the destructive part of the ABM missile. The main mission of the ABM missile is to bring the warhead section to the vicinity of the target, and use the latter to destroy the target.

A hand grenade usually consists of a shell, a firing device and a safety device (located on the handle; the lid of the handle is the safety lid).

The ABM missile is similarly made up of warheads, fuse and safety device.

The warhead is the chief part of the warhead section. A large amount of energy is stored there, to be used in the destruction of the target.

The fuse is used to initiate the explosion of the warhead. At the moment the power of the warhead can be utilized most effectively, the fuse "lights the explosives" and causes explosion.

As the name implies, the safety device is to ensure safety. Its function is to release the safety lock when the warhead reaches the hit region, so that fuse is in the strike position, to ensure that the warhead will not explode before the ABM missile is launched, and to cause self-destruction of the ABM missile in case it misses the target. This is similar to the action of the safety lid of the hand grenade.

The warhead section can be classified as nuclear warhead or non-nuclear warhead (i.e. regular warhead). ABM missiles usually employ nuclear warheads.

Once the following incident took place. An airplane that was in perfectly sound condition sustained damage on taking off - a hole was bored through it.

Nothing was fired from the airport to damage the airplane. The unfortunate

incident occurred as a result of a little sparrow heading toward the airplane while it was taking off.

The first case of a collision between a bird and a plane took place in 1912. When the famous pilot, Carl Rodgers, who crossed the continent, was flying over California, a sea gull collided with the airplane and caused the tragic death of the pilot.

How could a little bird damage an airplane? The answer lies in the high relative velocity.

Take, for example, a bird that weighs 100 g. If it hits an airplane traveling at the speed of 80 km/hr, the resulting impact will be approximately 30 kg, which is 300 times the weight of the bird, and very sizable indeed.

The ABM missile intercepts the target head-on. The relative velocity is extremely high (exceeding 8 km/sec.). Therefore, the pellets and pieces of the exploded warhead can cause great damage. When these pellets and pieces meet the warhead that is traveling at a very high speed, they can cause serious damage to the latter, which include inactivation of the fuse, premature explosion, damage to the warhead housing that could result in the warhead burning out when it re-enters the dense atmosphere.

The function of the propulsion system is to generate thrust to push the ABM missile toward the target.

ABM missiles usually are solid propellants. What is a solid propellant? The propellant used in the toy rocket fireworks is one example. It is the "fuel" used in the engine of the solid rocket. In Figs. 5-2 and 5-3, a solid-propellant rocket engine is shown. There are several types of solid propellants. The one

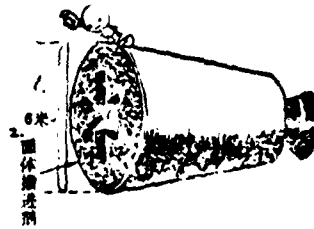


Fig. 5-2. Composite propellant cast into a large rocket engine.
Key: (1) Six meters; (2) Solid propellant.

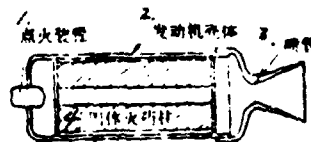


Fig. 5-3. Schematic diagram of the engine of a solid rocket.
Key: (1) Igniter; (2) Case of engine; (3) Nozzle; (4) Solid propellant charge.

used in the first and second stage of "SPRINT" is cordite.

The operating procedure is simpler for the solid rocket engine than the liquid rocket engine. The igniter is first activated electrically and gives off a flame that burns the propellant charge in the combustion chamber. The propellant charge then produces exhaust gases of very high temperature and pressure which expand while passing through the nozzle, and are forced out at a high speed, producing a thrust.

Solid rocket engines have many advantages over liquid rocket engines. For example, the propulsion system is simple, not requiring a complicated propellant feed system; the engine has a simple structure and is reliable; the solid propellant has a high density; the solid propellant charge is loaded into the engine well in advance, so that less preparation time is required before combat, which

is a definite advantage; less logistic service is required. These merits have made the solid rocket engine the natural choice for the ABM missile.

The function of the flight control system is to make sure that the ABM missile will not tumble and roll uncontrollably in the air, but will follow the desired path (trajectory) toward the target. An analogy is found in controlling the handle of a bicycle to make it go in a given direction. Symbolically speaking, the flight control system is the "pilot" of the ABM missile. It consists of transitional motion control and rotational motion control. If the ABM missile cannot maintain a definite direction in space, then not only would it be impossible to control it but also it would be hard to keep it flying without tumbling down or breaking in the air. Hence, it is necessary to control the attitude of the ABM missile. The system to accomplish this is the attitude stabilization system (or altitude control system). In other words, the function of the altitude stabilization system is to control the thrust direction, make the missile rotate about its center of gravity, and thus achieve the purpose of making the ABM missile fly in a stable manner. Stabilization is achieved through adjustment of the nozzles, or the magnitude and direction of the thrust of the rotatable motors. These small nozzles or rotatable motors are like little "hands" that control the ABM missile so that it flies in a stable manner toward the target, with a prescribed attitude (spatial position).

The system controlling the transitional motion of the ABM missile is called the guidance system. This system controls the motion of the center of gravity of the missile and makes it fly toward the target according to the guidance rule. To accomplish this, the deviation of the actual trajectory from the reference trajectory of the ABM missile has to be eliminated so that the center of gravity of the missile has the velocity and position conforming to those of the reference

trajectory. To do so, the trajectory parameters (position and velocity) of the target and the ABM missile are constantly measured and compared by means of the computer, allowing control commands to be formed to govern the motion of the center of gravity of the ABM missile until the target is hit.

The body of the ABM missile connects all the different parts and system to form a complete unit that is able to accomplish the mission of destroying the invading target. Fig. 5-1 is a schematic diagram of a three-stage solid-propellant ABM missile. The housing of the ABM missile is usually made of aluminum alloys, and reinforced with a steel frame.

Characteristics of ABM Missiles

ABM missiles being specifically designed for the purpose of countering offensive guided missiles (midrange, long range or intercontinental ballistic missiles launched from land or submarines), what characteristics should they possess? Before talking about these characteristics, let us first look at the properties of offensive guided missiles.

Intercontinental ballistic missiles (ICBM) fly at very high speeds reaching 25,000 km/hr. (This is more than 1,700 times the speed of a bicycle traveling at 15 km/hr. It will take the bicycle about half an hour to traverse the same path covered by the ICBM warhead within one second.) The total time of flight is short (about 30 minutes). If an ICBM warhead with range of 10,000 km is detected and acquired 4,000 km away, then there will only be ten minutes before the ICBM will land. It is undoubtedly fairly difficult to get rid of this ICBM within this short period of time.

The greatest difficulty lies in the very short advance-warning time. (Advance-warning time for ICBM can reach a maximum of only 25 minutes.) This has

placed a stringent requirement on the ABM missile. If tracking of an ICBM starts when it is 2,500 km away, it will be only six minutes before the warhead will land. Hence, "speed" has become the key to a successful interception. The ABM missile has to have high speed and acceleration. It has to be able to quickly meet and attack the target. Otherwise, it could be hit and destroyed by the invading guided missile instead.

Speed is required in the ignition of the rocket engine, in the combustion of the propellant, and in the exhaust of the exhaust gases. In the terminology of rocket technology, the thrust of the solid-propellant rocket engine (or booster) of the ABM missile has to be large, the specific impulse should be high, combustion rate should be high and the mass ratio should be high.¹ Only thus can one ensure that the ABM missile will accelerate to a speed of several kilometers per second, the acceleration reaching tens or over a hundred times of g ($g = 9.8 \text{ m/sec}^2$), which is equivalent to ten or over a hundred times the weight of the missile. Only then will the ABM missile be able to intercept the invading target at extremely high velocity.

The ABM missile should be able to move with flexibility, so that it can turn swiftly toward the target. This requires that the magnitude and direction of the thrust be adjustable. Hence the ABM missile should be equipped with dynamic engines.

The ABM missile should be resistant to high temperatures. When an ABM missile (especially a low-altitude interceptor) flies in the atmosphere, the

¹Specific impulse is the ratio of thrust to consumption per second. Mass ratio is the ratio of the total mass to the mass at the time the engine is shut off. Consumption per second is the weight of a propellant consumed per second.

temperature at its surface can reach over a thousand degrees owing to atmospheric friction. If the ABM missile is not heat-resistant, then it would probably have burned up before its mission is accomplished. Hence, the construction material of the missile body consists of high temperature paints or heat-resistant material.

In general, the engine of an ABM missile uses solid propellant and possesses such characteristics as large thrust, fast acceleration, short working time (high combustion rate), ease of starting, short preparation time for launching, easy maintenance and reliability.

An ABM missile that possesses the above characteristics meets the necessary conditions for "catching" the target, but not the sufficient conditions.

What are the means for enabling the ABM missile to maneuver and actively intercept the target?

The ABM must maneuver by the use of a pivoted nozzle by which the magnitude and direction of engine thrust are changed. This can also be realized through the use of secondary exhaust jets (Figs. 5-4 and 5-5) which interact with the jet flow to control the thrust.

Fig. 5-4. Secondary jet in a solid-propellant engine.

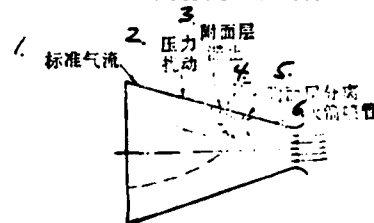


Fig. 5.5. Control of thrust vector by means of secondary jet.
Key: (1) Standard gas flow; (2) Pressure disturbance; (3) Stagnation of boundary layer; (4) Jet flow; (5) Separation of the boundary layer

What is secondary jet vector control?

The Yangtze River flows smoothly towards the east, collecting many tributaries on the way. If you are at Wuhan and looking at the Yangtze River where it meets the Han River, you will see that the Yangtze River first "yields" to the Han River, and then devours it.

The secondary jet flow method employs the same mechanical principle as that involved in the "yielding" of the Yangtze River. The method is to inject a flow (liquid or gas) into the nozzle of the engine in much the same way as the Han flows into the Yangtze. This produces in the main flow of the engine nozzle an obstacle so that a small positive pressure develops at the nozzle wall near the jet inlet. This causes a change in the magnitude and direction of the thrust. Fig. 5-6 is a schematic diagram of the secondary jet flow method.

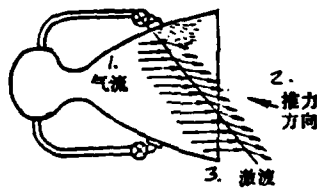


Fig. 5-6. Stimulated waves are produced, changing the direction of the jet flow.
Key: (1) Flow; (2) Direction of thrust;
(3) Stimulated waves.

The secondary jet flow method of controlling the thrust vector causes the sidewise force to increase, and thus achieves the purpose of varying the magnitude and direction of the thrust.

Examples of Foreign ABM Missiles

To further understand the structures and characteristics of the ABM missile, we will take a look at some of the foreign ABM missiles.

1) The "SPARTAN" - High-Altitude Interceptor.

The "SPARTAN" is a high-altitude interceptor with average velocity of 2.2 km/sec and altitude of interception of 160-480 km.

The "SPARTAN" is a winged three-stage solid-propellant guided missile. The first stage is an accelerator (booster), about 5.4 m long, placed in the body of the missile with a diameter of 1.1 m. The second stage is the main engine used for acceleration and dynamic flight. Hence, the "SPARTAN" has definite dynamic capabilities, and can "catch" the target in accordance with the guidance commands. The third stage contains, besides the spherical engine, a nuclear warhead section, energy sources, electrical power supply, control devices, the autopilot, the turntable and the missile-carried computer. For the structure and external features see Fig. 5-7.

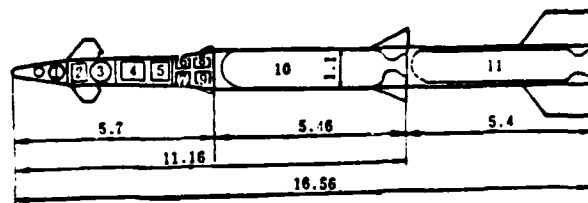


Fig. 5-7. Schematic diagram of the structures and external features of the "SPARTAN."

Key: (1) Warhead section; (2) Steering controls; (3) Engine; (4) Energy source; (5) Power supply; (6) Control system; (7) Autopilot; (8) Turntable for stabilization; (9) Computer; (10) Main engine; (11) Accelerator.

The "SPARTAN" carries a thermonuclear warhead that is equivalent to several million tons of TNT. When the warhead explodes in space, 70-80 percent of the energy is released within one-tenth of a second in the form of invisible X-rays. This damages the heat-resistant layer of the warhead, causes the internal materials to vaporize, and destroys the warhead. The radius of the destructive range of the warhead of the "SPARTAN" is approximately 8 km.

Although the "SPARTAN" has definite dynamical capabilities and can "catch" a target, it cannot equal the task of "catching" a group of targets containing many baits. To find the invading warhead in the group of false targets is as difficult as identifying a bad buy from within a group of a hundred persons.

This is to say that before the problem of high-altitude target discrimination is solved, it will be hard for the "SPARTAN" to "catch" the true target. Is it feasible, then, to destroy all the targets, true and false alike? The "SPARTAN" is limited by the accuracy in guidance and the warhead will not explode in the target group. Besides, the damaging power of the warhead section is still limited. Hence, the "SPARTAN" is not capable of destroying all of the true and false targets distributed in a tubular shape spanning several kilometers (see Fig. 5-8).

2) The "SPRINT" - Low-Altitude Interceptor

The interceptor "SPRINT" has an average velocity of about 3.2 km/sec and an acceleration exceeding 100 g.

The "SPRINT" is a two-stage solid-propellant guided missile with a cone-shaped body whose base is 1.37 m in diameter. The tail section is a honeycomb structure of 9.5 mm thick aluminum made up of two conic sections of different apex angles. Its outer wall is the smooth outer surface of the body of the missile. The inner wall is an extension of the nozzle of the first stage engine. The space between the inner and outer surfaces of the tail section is where the thrust control system of the first stage engine is seated.

Thrust control is achieved in the first stage by means of secondary liquid jet flow. In the second stage, the thrust control is achieved through four small control surfaces located at the bottom of the second stage. The guidance and stabilization equipment are located between the warhead and the second stage engine.

After the "SPRINT" has reached its maximum velocity, the temperature at the surface is higher than that inside the engine. Hence, the body of the missile has to be covered with such ablation materials as silica-phenolics for protection of the guidance and stabilization systems.

In order to rapidly intercept and "lock on" to the target the "SPRINT" employs a solid propellant with a rapid combustion rate and relatively high energy - a modified double-based chemical. After the first stage engine burns completely out and drops off the "SPRINT" depends on its basic aerodynamic contour carries out limited maneuvers, thereby "locking on" the target.

Figure 5-9 is an illustration showing the appearance of the "SPRINT".

The "SPRINT" is not an agile craft, it "pay special attention" to the fact that target capabilities are also very different. This is the reason it "runs" slowly and acceleration is rather low; its lack of agility, maneuverability and guidance accuracy are not a problem.



Figure 5-8. ABM Intercept



Figure 5-9. Anti-ballistic missiles
(a) "SPARTAN"; (b) "SPRINT"

VI. COMMAND CENTER - THE BRAIN IN THE BMD WEAPON SYSTEM

Let us see what disaster would result from a confusion of command.

The incident occurred at an international airport on Spanish territory on March 27, 1977. It was Sunday and the airport was crowded with airplanes. At 1440, International Standard Time, a Boeing 747 jet plane of the Netherlands Air Line was accelerating on the runway.

This monstrous airliner, weighting 350 tons, with wingspread approximating 60 m and length 70 m, made deafening booming roars as it was pushed forward by the strong thrust produced by four turbine engines. It went faster and faster on the runway until it reached a speed of 300 km/hr and was about to take off.

Suddenly, another jumbo airliner of the same size taxied across the runway in front of the first airplane. When the Netherlands pilot became aware of the huge monster that suddenly appeared out of nowhere, it was already too late to brake or turn the plane. The 300 tons plus airplane continued to rush on like crazy, at a speed of 300 km/hr.

In no time a loud crash was heard. The Netherlands airliner crashed into the fuselage of the other airplane. A series of explosions resulted and the parts of the airplanes were scattered about. Some fragments were flung to places four or five hundred meters away. The Netherlands airliner was the first to catch fire. The blazing fire melted the pitchblende on the runway.

The other airplane belonged to PAA and was also a Boeing 747 air liner. It was a transit airplane that arrived from Los Angeles.

This was the worst airplane collision that occurred in international history. The death toll numbered 576. The cause was apparently a confusion in the air traffic control system. From this, one can see the importance of the responsibility of the command and control system.

The command and control system has always played a major role in the history of war. The command center in the command and control system, in turn, is of great importance in the BMD weapon system. Its function is equivalent to that of the human brain. It coordinates the various subsystems of the BMD weapon system so

that it may actively "catch" the target. If the commands go out of order, the defense system will face the danger of being destroyed.

Functions of the Command Center

The command center is the decision-making organization of the BMD weapon system. It has to analyze and synthesize all information, make decisions regarding different invading targets, and report intelligence to the military staff so that orders of counterattack can be issued and the target destroyed. It is a completely automated system that can centralize all subsystems, personnel and BMD weapons, and effectively command and move them so as to bring the combat ability into full force and annihilate all invading "enemies."

Stated simply, the duty of the command center is to promptly provide accurate intelligence for the commanding organization of the nation (commander in chief or the general staff), and direct the operations of the subordinate departments (systems). Some activities are: 1) watching the development of the situation and the activities of the troops on both sides; 2) evaluating the alarm and estimating the threat of the target; 3) maneuvering the BMD troop in preparation for the counterattack; 4) counterattacking the invading target by ordering the launching of the high- and low-altitude interceptors, and evaluating the outcome of the interception; 5) reorganizing and commanding the BMD troop to prepare for counterattack, or undergoing a second counterattack; 6) announcing "all clear."

To be able to make decisions in a very limited time, the command center has to automatically synthesize information on the situation and the target, automatically process and sort the target information, automatically process data related to ABM missile's combat preparation and combat, choose path of interception and order the launching of the ABM missile, and display the ABM missile and target information on the fluorescent screen and indicators.

The computer is the main equipment used in formulating the decisions. The function of the computer of the command center is to make correct judgments based on information about the target and the ABM missile, and provide the commanding personnel with direct intelligence and best scheme of combat via large display screens and other display devices. Hence, the computer does the "thinking" for the command center. Only after calculation by the high-speed computer can any command be issued. To increase reliability, calculation is usually performed on several computers in parallel and self-checking and diagnostic techniques are employed. If something goes wrong with the computer system, accidents are sure to ensue. Such an incident took place once in the United States when a problem in the computer caused a false alarm to prepare for a nuclear war.

The incident happened in early winter one year. On this day (November 9), a computer serving the North American Air Defense Headquarters had a disorder which caused a false signal to be given, indicating that the enemy was attacking. The command center immediately sounded off the alarm, and many fighter-bombers took off to meet the enemy, which was nonexistent. The false alarm lasted six minutes.

The command center generally includes the following subsystems: combat, reconnaissance, communication and weather forecast.

The combat system is equipped with several computers and signal display devices including several large fluorescent screens, automatic indicators and large-screen displays (usually around 100 sq. in.). Information on enemy space activity, ABM missile readiness and the activities of other systems is constantly fed to the combat system.

Combat commands, intelligence and combat effectiveness are directly displayed on the display devices of the combat system to enable the command personnel to

control the entire situation with ease. The entire process from detecting the target to destroying it is displayed and directly viewed by command personnel. The computer causes the diagrams, curves and numbers to be displayed.

The weather forecast subsystem provides the command center with weather information concerning clouds, ionosphere, temperature, snow, rain and fog. The tools used include weather satellite, weather radar, balloons, etc.

Communications is the "nerve center" that connects all the other subsystems. It is a vital part in war. Modernized warfare especially demands smooth and accurate flow of commands and good coordination among the various systems. There are many examples in history of successes and failures attributable to communications, the Pearl Harbor incident and the Middle East crisis being two of them.

One day during World War II, a radar located on the northern seashore of Oahu detected an invading Japanese airplane. Owing to a delay in the communications system, this important alarm could not be delivered to the air defense headquarters in time. As a result, the U.S. Air Force suffered great loss from the surprise attack on Pearl Harbor. This is the well known Pearl Harbor incident. In 1973, during the Middle East crisis, orders to be on guard were given by the U.S. military command center, and reached each and every headquarter of the joint troops and task forces within three minutes.

Failure in defense by the EMD weapon system could result from misjudgment or a wrong decision by the command center, malfunctioning of the command system, the various subsystems not being well coordinated or bad timing. In such cases, even the defense system itself could be destroyed. Hence, it is very important that the automatic command center operates reliably and effectively.

Advance-warning time for ICBM invasions is usually only 10 to 20 minutes. That for the mid-range guided missile is even shorter (a few minutes to a little over ten minutes, as shown in Table 1). Time available for counterattack is extremely limited. If commands were delivered through telephones or telegraphs, then one would have no hope of carrying out the defense measures. Hence, the command system requires speed, accuracy, reliability and security. The ideal "operator" of such an automatic system is none but the high-speed computer system mentioned above.

We need to clarify here that there are weaknesses in the present command and control systems. For instance, if the large-scale antenna arrays are damaged by nuclear weapons, then the command and control system would be cut off from the information source or from communication with the other systems, resulting in total or partial paralysis of the weapon system. The use of small-scale communications network can circumvent this difficulty. These are convenient, flexible and less susceptible to destruction by nuclear weapons.

Functions of the Electronic Computer

It is essential for the command and control system to have a complete computations network which includes large-scale, advanced computers, and which can be a mixed-mode parallel processing structure. These large computers are connected to small processors, distant terminals and display devices, forming an effective command and control system.

The high-speed electronic computer is an equipment for performing calculations on data, signal processing, or automatic controls. It can perform calculations in accordance with programmed instructions, organize logical processes based on conditions created during a process, and execute the automated control

processes with regard to the BMD weapon system, such as issuing orders and evaluating effects.

Based on the information it receives regarding the targets, the computer makes assignments to the various parts of the BMD weapon system, calculates the path of interception for the ABM missile and formulates the various control commands to guide the missile toward the target.

The computer is a versatile piece of equipment. Besides processing signals for the process of interception and automatic control of the system, it also performs the following duties:

- 1) It is used to control the radar beams to repeatedly make observations on the invading target. It then analyzes the reflected signals and performs calculations to identify the type of the targets (guided missiles, meteorites, satellites, etc.), and decides which are true or false. It has to make sure that no warhead is lost track of. If the warheads are so numerous that they saturate the radar tracking capacity, then the computer has to choose among these the more important ones and keep track of them.

- 2) The computer constantly calculates the position of the radar beam in the next scanning cycle, and automatically adjusts the radar transmitter and receiver to optimum operating condition. When it is required to determine the precise coordinates of the target, the computer causes the broad high-speed scanning beam of the antenna to narrow down. Of course, it can similarly decrease the pulse width to increase distance resolution.

- 3) The computer controls the radar so it operates at optimum beam width and pulse width and can identify the warhead from a group of targets, obtain as much information as possible regarding target features and characteristics (i.e. target

shape, size, attitude, surface material and surface structure), and compare this information with pre-recorded standard signals for various targets for the purpose of discrimination.

4) If the target engages in tactical maneuvers and switches from one trajectory to another, then the computer commands the radar to use higher frequencies for observation and calculates and predicts for the BMD system the tactical trajectory of the target.

5) The computer quickly exchanges information obtained from the various radars. It examines, classifies and processes the various measured data. It supervises and checks to see if the BMD weapon system is working properly.

The computer of the command center has to fulfill the following requirements:

1) It should be able to perform calculations at a very high speed. It has to make several million to several hundred million operations per second and give accurate, reliable results. It should be able to process and exchange signals at a high speed, quickly predict target trajectory and calculate intended hit point.

2) It should have "memory," and be able to store vast amounts of target data, ABM missile data and combat schemes at appropriate addresses.

3) It should be able to make "logical judgments," and help command personnel analyze the various intelligence and make decisions.

The computer in the U.S. BMD weapon system, "NIKE-X," is a large-scale computer especially designed for BMD weapon systems by UNIVAC. It has the capability to perform one hundred million mathematical operations per second with 25 processors working in parallel. Besides performing calculations related to the trajectories and guidance commands for the high-altitude interceptor "SPARTAN" and

low-altitude interceptor "SPRINT," this computer has to carry out other duties such as radar management.

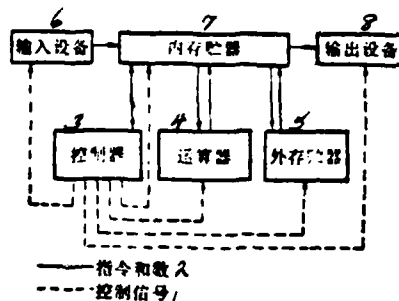


Fig. 6-1. Block diagram of the computer.

Key: (1) Control signal; (2) Commands and numbers; (3) Controller; (4) Processing unit; (5) Peripheral memory storage; (6) Input facility; (7) Central memory storage; (8) Output facility.

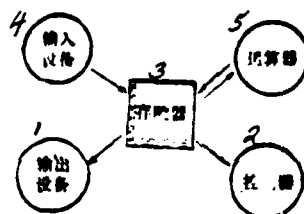


Fig. 6-2. The main constituent parts of the computer

Key: (1) Output facility; (2) Controller; (3) Memory storage; (4) Input facility; (5) Processing unit.

The computer consists of five parts mainly, viz. (logical) processor, controller, memory storage, input-output facilities and power supply system, as shown in Figs. 6-1 and 6-2.

The input device of the computer first records the raw data and instructions for calculation, such as programs (the most prevalent being written in the FORTRAN and ALGOL languages), on punched paper tapes or cards, and then reads them into the memory storage. The input facilities are usually electro-optical in nature, transforming mechanical signals on the paper tape into electrical signals. These

can feed over a thousand symbols (numbers) into the computer.

The memory storage is used to store raw data, mathematical operations and results of calculations. It has the ability to "remember" all the information needed in the operation, which can be retrieved very fast. There is usually a central memory storage and a peripheral memory storage. The central memory storage stores data that will be needed in immediate calculations, the capacity being in general from several tens of thousands to several hundreds of thousands numbers. The peripheral memory storage is the place to store data that will not be used immediately. It can usually hold over ten million numbers. The computer uses the binary number system which has the following characteristic: There are only two basic numerals, "0" and "1." In operations, one carries over to the next higher place whenever the numerals add up to 2. The number 5 in the decimal system becomes "101" in the binary system (Table I).

Table I

The decimal and binary systems

<u>Decimal system</u>	<u>Binary system</u>
0	0
1	1
2	10
3	11
4	100
5	101
6	110
7	111
8	1000
9	1001
10	1010

The processing unit performs the various mathematical operations of the computer. It is made up of the registers (electrical circuits serving as temporary storage for the operators, operands, and results of operation) and the adder. Its main function is to perform the operations of addition, subtraction, multiplication

and division. It can also perform logical operations. The processor operates at a very high speed, which is the main factor limiting the speed of the computer. The shorter the time it takes to do calculations, the faster the computer.

The output facility puts out the final results of the computations in definite formats (eg. in the form of printed data, or drawn curves or diagrams). There are many types of output devices. These include the commonly used line printer and displays.

The function of the controller is to command and control the various parts to work in coordination. It controls the entire operation and ensures that the entire process proceed automatically. When an external signal is likely to be received, the controller enables the computer to perform real-time control on external processes. The controller is one of the more complex components of the electronic computer.

The power supplies supply the power needed by the various parts of the computer. The requirement on the power supplies are high stability and reliability. Fig. 6-3 shows the function of various parts of the computer.



Fig. 6-3. Functions of the electronic computer.
Key: (1) Computer operator (control);
(2) Paper (storage); (3) Processor
(mathematical operations).

At present, general-purpose computer systems have taken the place of special-purpose computers in BMD weapon systems. Under the conditions of a nuclear war, the important thing is to protect the electronic computer from being damaged by nuclear effects, including γ -rays, x-rays, nuclear beams and electromagnetic pulses, so that the command and control system may function normally.

In an actual combat, the computer functions in the following manner. Immediately after the radar detects the invasion of enemy guided missile, the computer (several large ones or one giant system) speedily processes the measured signals, discriminates between the true and false targets, calculates target trajectory and landing point, calculates intended hit point, intended hit time, and damaging power of the warhead, and displays all the information on the display devices at the command center. Once the responsible personnel at the command center have made a scheme for counterattack, the combat orders are issued from the command center, and the surface guidance system formulates control commands via the computer, based on ABM missile and target information. These control and guide the ABM missile to intercept the target.

VII. ADVANCE-WARNING SYSTEM AND "CLAIRVOYANCE"

The skies being so vast and deep, how can one know if an "enemy" is attacking? And how can one be sure that the ABM missile, flying toward the target, will actually hit the "enemy"?

The radar, which people call "the clairvoyant," keeps watch over the aerial domain. The numerous "eyes" distributed all over the country - long-range radars, extra-long-range radars, advance-warning satellites, etc. make up regional or national alarm networks, i.e., the advance-warning system. This system is huge, complex and automated. It is responsible for detecting the targets, sounding the alarms, and acquiring and tracking the targets.

The operation of the advance-warning system is pretty much the same as that of radars detecting and tracking airplanes, often seen on the movie screen. The advance-warning satellite or the sub-horizon radar watches for invading guided missiles day and night. Once the target (guided missile in flight or being launched) is detected, alarm is given, the target is tracked, and the target signals measured are transmitted to the long-range tracking radar which tracks the target. The computer calculates the number of targets, orders and classifies the targets, estimates the location of the landing point and extent of possible damage, calculates target trajectory, estimates the location of the hit point, and furnishes the BMD weapon system with various information. The advance-warning system sends intelligence to the command center at all times, and also delivers it to other subsystems of the BMD weapon system in time.

Detection of the target is achieved through the advance-warning satellite, sub-horizon radar and long-range target tracking radar.

Why is it necessary to form such an extensive advance-warning network?

First of all, one can never know which direction the enemy is going to be coming from. Secondly, the invading guided missile has high speed, high peak of trajectory, long range, great power, and the ability to employ various means for defense penetration. Hence, only by forming a nation-wide or regional advance-warning system can one hope to deal with guided missile attack from any direction and provide as much warning time as possible.

From Table 1, one sees that the total flight time is about 30 minutes for an ICBM whose range is 10,000 km.

Owing to the spherical shape of the earth, even a long-range warning radar with an effective distance of 5,000 km cannot "see" the ICBM until 15 minutes after its launching, i.e., when it has already flown half-way toward the defense region. (See Fig.7-1.)

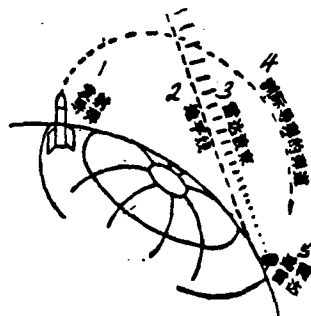


Fig. 7-1. Long-range radar detecting target.
Key: (1) Launching of guided missile; (2) The horizon; (3) Radar beam; (4) Trajectory of ICBM; (5) Long-range radar.

In order to detect the target as soon as possible, one needs to employ the advance-warning satellite and the sub-horizon radar. How can advance-warning satellite and the sub-horizon radar "look" around the curved surface of the earth and detect the guided missile that has just been launched?

Advance-Warning Satellite

As a saying goes, "Stand high and you'll see far."

The satellite (man-made earth satellite) is high up there, several hundred to several tens of thousands of kilometers aboveground. No wonder it can "see" very far. Hence, it is a good idea to use the satellite for reconnoitering missile launching.

What is an advance-warning satellite? Stated simply, it is a satellite that is used for detecting targets and giving warning.

The advance-warning satellite is one of the important means of reconnaissance for the advance-warning system. It can effectively detect the launching of guided missiles; not only is the warning time long, but the area covered is very large (several tens of thousands of square kilometers), and the system is immune to interference by weather conditions and enemy radio waves. (See Fig. 7-2.)

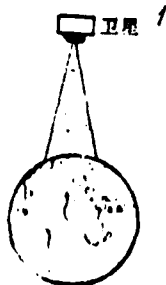


Fig. 7-2. Advance-warning satellite.
Key: Satellite

The advance-warning satellite is generally placed in a synchronous orbit (at an altitude of about 35,800 km). At this altitude, the satellite orbits the earth once every day. Hence, its angular velocity is the same as that of the earth, and the satellite appears to be stationary when viewed from the earth. Therefore, it is also called a stationary satellite.

The subjects of the advance-warning satellite being launched, flying along its trajectory and entering the synchronous orbit have been discussed in the book titled "Man-Made Satellites And Manned Spaceship."

The advance-warning system is equipped with various remote sensing devices:

- 1) Infrared sensors, used in remote sensing the characteristics of a very distant object. These can detect infrared radiation. When the guided missile is ignited and is lifting off, a large amount of infrared radiation is present in the exhaust gases given off by the missile. The infrared sensor senses the radiation and thus detects the launching of the guided missile.

- 2) Optical sensors, such as those used in video camera equipment. When the guided missile is launched and lifts off, the camera equipment takes pictures of the moving target and sends them to the air defense command center.

These two types of sensors can complement each other to eliminate false alarms. Generally speaking, after the infrared sensor on the satellite has given alarm signals, the air defense command center has to analyze the pictures transmitted from the video camera equipment in order to double-check the validity of the alarm.

We will illustrate the operation of an advance-warning satellite by taking as example an early version of an advance-warning satellite developed abroad. That satellite is about 3 m tall and 2.7 m in diameter. It carries at one end an infrared telescope 3.6 m long and 1 m in diameter. Hence, the total height of the satellite is 6.7 m and the total weight, 900 kg, as shown in Fig. 7-3.

From the figure, it is clear that the advance-warning satellite achieves stability through the use of thrust-producing nozzles, obtains electrical power through the solar panel which is oriented toward the sun by means of solar sensors, and has sensors for detecting nuclear explosions.

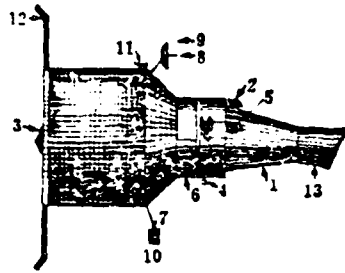


Fig. 7-3. Structures of a type of advance-warning satellite.

Key: (1) Infrared telescope; (2) Optical sensor (video camera); (3) Detector for radiation from nuclear explosion; (4) Satellite detector in the attitude-control system; (5) Detector in attitude-orienting system; (6) Electronic equipment aboard; (7) Antenna for transmitting signals obtained by infrared sensor back to surface; (8) Antenna for transmitting video pictures back to surface; (9) Command-receiving antenna; (10) Auxiliary detector for radiation from nuclear explosion; (11) Triaxial attitude-controlled nozzle providing thrust; (12) Solar panel; (13) Solar screen for protecting the telescope and the infrared remote sensor.

The infrared sensors aboard the satellite is an array of 2,000 lead sulfide infrared detectors. Each detector covers a surface area on the earth of 13.7 square kilometers, the total surface area covered being 27,400 square kilometers. When the satellite is operating, the sensor makes a regular scan of the covered area. Electrical signals from the sensor are regulated, amplified and digitized before being transmitted back to earth. The optical sensor is a type of video camera equipment. After the infrared sensor has detected the launching of a guided missile, the optical sensor is automatically controlled to orient itself toward the guided missile and the satellite automatically transmits video pictures back to earth. It takes only a short time, generally within one minute after launching of the missile, for the satellite to detect the missile. However, the advance-warning satellite also has its shortcomings. For example, the sensitivity of the infrared sensor decreases with operating time; and there is the

problem of false alarms. Hence, it is necessary to combine the advance-warning system with sub-horizon radar, long-range tracking radar or air-borne radar to form an advance-warning network.

"Clairvoyant" - the Radar

The radar is also termed the radio wave locator. It is an electronic equipment that sends out radio waves and then receives the waves reflected from a distant target, thus detecting the target. The radar can be used to detect flying targets such as an ICBM several kilometers away, and determine their distance, azimuth and velocity. It is an important constituent of the air defense system. The targets include various targets in the air, on the water or on the ground.

The radar is generally made up of a timer, a transmitter, a receiver, an antenna, a display device and a computer, as shown in Fig. 7-4.

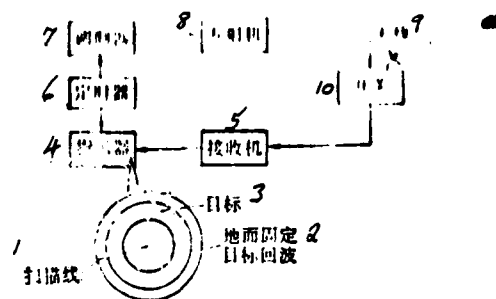


Fig. 7-4. Main constituents of a radar.
Key: (1) Scanning line; (2) Waves reflected from a target on the ground; (3) Target; (4) Indicator; (5) Receiver; (6) Timer; (7) Regulator; (8) Transmitter; (9) Antenna; (10) Switch.

As the radar enables men to detect the target and determine its location even if it is far beyond the visual range, and even if it is obscured from visual detection by darkness, fog, clouds, smoke, etc., people call it the "clairvoyant." Some even say that radar is the sentry and searchlight on the battlefield, the

informer of the commander, or the eagle's eye. In 1938, the British first installed a short-wave seashore warning radar.

The radar operates on the following principle. The transmitter emits very strong radio waves which hit the target and are reflected back to the receiver. Based on these reflected waves, a picture of the target can be made and the target characteristics can be determined, as shown in Fig. 7-5.

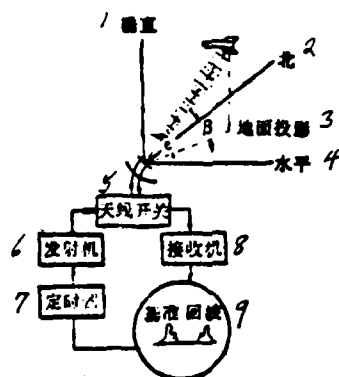


Fig. 7-5. Block diagram of operating principle of radar.

Key: (1) Vertical; (2) North; (3) Projection on surface of earth; (4) Horizontal; (5) Antenna switch; (6) Transmitter; (7) Timer; (8) Receiver; (9) Standard reflected wave.

The requirements on radars used for different purposes are different. For the guided missile advance-warning radar which deals with invading targets that are fast, maneuverable and can employ various means for defense penetration, the following properties are required:

1) It should be effective over a very large distance so that it may detect and track invading targets several thousands of kilometers away, and provide sufficient warning time for the ABM missile. Hence, it would be best to be able to detect the guided missile at or very soon after launching.

2) It should be able to accurately determine the trajectory of the invading target, i.e. the trajectory parameters and the hit point and landing point.

Target trajectory data can be expressed in terms of distance R (the distance between the radar station and the target), azimuth angle β (the angle between the line joining the radar station and the target and the line pointing to the north), angle of inclination ϵ (the angle formed by the line joining the radar station and the target and its projection on the earth's surface), and the rate of change of distance (Fig. 7-6). Given these four parameters, or just the first three, one can obtain mathematically the target trajectory, hit point and landing point.

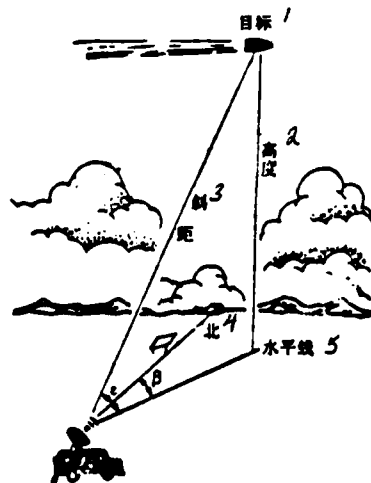


Fig. 7-6. Schematic diagram of radar making measurements.

Key: (1) Target; (2) Altitude; (3) Slant distance; (4) North; (5) Horizontal Line.

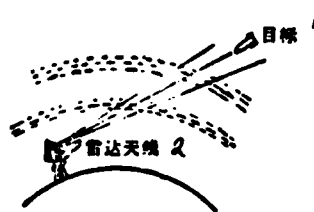


Fig. 7-7. Target detection using a common radar.

Key: (1) Target; (2) Radar antenna.

3) It should be able to effectively identify the target. It has the ability to discriminate the true target from the false targets and to determine the type of the target based on the target characteristics.

4) It should be able to track many targets, some of which are maneuverable. It should have the ability to acquire all these targets.

5) It should have high reliability and be able to process data accurately.

As electromagnetic waves travel in straight lines in space, the ability of target detection of common radars is limited by the shape of the earth. These radars can only detect those targets that are above the horizon, but not the ones that lie below the horizon. (See Fig. 7-7.)

What should one do if the guided missile launched by the enemy is located below the horizontal line passing through the radar station? In that case, one should employ the sub-horizon radar.

Sub-Horizon Rules

The electromagnetic waves emitted from the sub-horizon radar can "bend" in the ionosphere and reach a target that is located below the horizon. (See Fig. 7-8.)

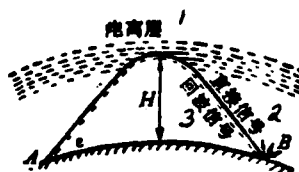


Fig. 7-8. Signal reflection at the surface.
Key: (1) Ionosphere; (2) Direct signal; (3) Reflected signal.

The concept of designing a sub-horizon radar was proposed in 1946. Afterwards, attempts were made in the United States to use it for solving the problem of early guided missile detection. Since then, the study and fabrication of the sub-horizon radar has begun.

The short electromagnetic waves that reach the surface of the earth after

reflection from the ionosphere can be scattered by the ionosphere in all directions. Thus, part of the scattered energy will retrace the signal path and return to the original point of emission (radiation). If an object (such as guided missile or aircraft) is present in the path of propagation of the electromagnetic energy, then that object will reflect part of the energy, which will then be recorded at the point of emission. (See Fig. 7-9.) This is the basic principle of operation of the sub-horizon radar.

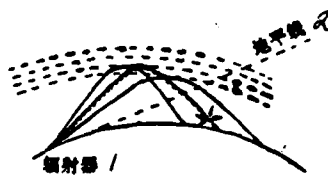


Fig. 7-9. Signal reflection from an object.

Key: (1) Emitter; (2) Horizontal line.

Accordingly, the range of action depends on the span of the jump which in turn depends on the angle of inclination ϵ and the height H (variable) of the reflective layer of the ionosphere. In general, the range of action is about 3,800 km for a sub-horizon radar that operates within the range of a single jump.

Depending on the manner of propagation of electromagnetic waves, a sub-horizon radar is either a forward-scattering or a backward scattering sub-horizon radar.

The transmitter and receiver of a forward-scattering sub-horizon radar are usually placed a long distance apart from each other, as shown in Fig. 7-10. After the electromagnetic waves are emitted, they are bumped back and forth between the ionosphere and the surface of the earth until they reach the receiver at another location. When a disturbance in the atmosphere is caused by the launching of a guided missile, it shows up as a variation in the received signal. The presence

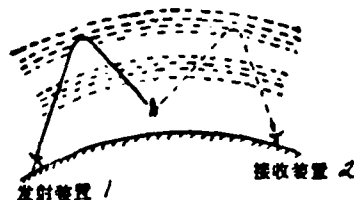


Fig. 7-10. Forward-scattering sub-horizon radar.

Key: (1) Emitting equipment; (2) Receiving equipment.

of the guided missile can thus be detected. Such radars have the advantage of being simple in operation. However, they can only indicate the presence and approximately direction of the target and are unable to determine target distance and other data.

The transmitter and receiver of the backward-scattering radar are placed at the same location (as shown in Fig. 7-9). The electromagnetic waves emitted from the emitter are short waves which after one or several bounces between the ionosphere and the surface of the earth can reach below the horizontal line passing through the emitter. After the waves hit the target, the reflected waves go back to the receiver. After signal processing, the target below the horizon will be revealed.

This type of radar not only can indicate the existence and location of the target, but also can determine the distance R of the target from the time delay Δt between the emitted signal and the received signal. ($R = \frac{1}{2} C \times \Delta t$; $C = 3 \times 10^8 \text{ m/sec}$ is the speed of propagation of the electromagnetic waves). Furthermore, it can determine the velocity of the target from the Doppler effect.

Because the sub-horizon radar operates in the short wave range, interference (from variations in the ionosphere, thunder) and other problems arise. Hence, an

important requirement which also becomes a disadvantage is that the sub-horizon radar have an emitter of high power and very large antenna, so as to increase the systems resistance to interference and improve the techniques for signal processing.

The chief advantage of the sub-horizon radar are its ability to detect targets lying below the horizon, its long range of detection (3,800 km with a single bounce, 7,600 km with a double bounce), large area coverage, and its ability to provide about 30 minutes of advance-warning time for the BMD weapon while a common radar can only provide three to 15 minutes warning time. However, the measurements are not very accurate, especially those made on the middle portion of the trajectory of the invading guided missile. A U.S. sub-horizon radar, for example, has a resolution of about 16 km for distance measurement, and several degrees for measurements on the azimuth angle. Moreover, it has poor viability, the antenna has a large size (eg., the U.S. "Polar Cap IV" radar has an antenna of 400 m in length and width of 60 m) and is exposed on the surface of the earth. This makes it susceptible to being hit and damaged, and being disturbed by nuclear explosions that interfere with the ionosphere. To overcome these difficulties, more efforts have to be made to study the fundamental properties of electromagnetic propagation, the variations and utilization of the ionosphere (such as choosing the optimum operating frequency and projection angle), and the technology of making fast swept-frequency and high power emitters, and of signal processing (so as to extract useful information from the weak reflected waves in spite of interferences). Hence, the sub-horizon radar should be used in combination with long-range searching and tracking radars, so that these may complement one another.

Long-range or extra-long-range acquisition radar (also called long-range advance-warning radar) is also a constituent part of the advance-warning system.

The commonly employed types are the single-pulse radar and the phased-array radar, the latter being more prevalent abroad.

Phased-Array Radar

What is a phased-array radar?

"Phased" refers to the fact that the phase of the electromagnetic waves emitted from the antenna can be controlled, and "array" refers to the fact that this radar is made up of thousands of radiating units arranged in a regular pattern, with columns and rows, as in an array. Thus, the phased-array radar is an antenna array made up of many radiating units, whose beam direction can be varied by controlling the phase of the waves emitted from each unit. It is one type of electronic scanning radar that does not have to move physically. Hence, it can track invading targets coming from any direction at any time.

The phased-array radar differs from the common radar mainly in that it has thousands of radiating units, a phase shifter and an actuator for shifting phase. A key point in the antenna is the quality of the phase shifter, which depends on a computer for shifting phase at a high speed. Secondly, phased-array radar is a system that contains highly automated controls. The control of the beam and the variation of the operating parameters are all accomplished automatically.

Because the phase of the signal emitted from each unit is controlled by the computer, the system is fast, flexible, accurate and reliable. The superiority of the phased-array radar lies in the following:

- 1) There is no inertia in the electronic scanning. The beam direction can be changed within one microsecond. This is a million times faster than mechanical scanning. The very high rate of data acquisition is just what the EMD system requires. Furthermore, the single beam is divided into several portions to

simultaneously perform many functions, such as searching, acquiring and tracking.

2) The system is multi-functional. Through the control of the phase of each unit, many beams can be formed that operate independently (and have adjustable power and gain) to simultaneously search and track separate targets. It can also form just one high-power, high-gain beam to search aerial regions a great distance away, and broaden the beam so as to speed up the searching. In addition, the use of many beams enables the system to simultaneously engage in many activities, such as searching, acquiring, discriminating, tracking and guiding the ABM missile towards the target. Hence, one phased-array radar can take the place of several different types of radar.

3) The entire operation of the phased-array radar is controlled by the high-speed electronic computer and is completely automated. The computer program allows for adjustments to be made in accordance with the changing motion of the target in space, and formulates the optimum operating scheme accordingly. It actively controls the beams and rationally allocates the power to meet the various complex requirements. Thus, this type of radar is self-adjustable.

4) In large-scale phased-array radars, the radiating units may be powered by several high-power signal sources or several hundred to several thousand low-power signal sources. Hence, the total emissive power can reach a very high order of magnitude resulting in a long range of action.

5) The system being made up of a multitude of small radars, when some of the small radars break down, the overall operation of the system will not be seriously affected. In other words, the system has high reliability.

6) As the antenna array is physically fixed, it can be made very sturdy and resistant to shock waves produced in nuclear explosions.

Thus, one can see that the beam of the phased-array radar is very flexible and variable. Under the control of the high-speed computer, it can perform high-speed scanning and other functions, such as exploring, tracking, discriminating and order and classify spacecraft orbiting the earth and invading guided missiles. Hence, the phased-array radar can meet the demand of ballistic missile defense fairly well.

Single-Pulse Radar

The single-pulse radar is commonly employed for accurately tracking the target and for target discrimination.

What, then, is a single-pulse radar?

The term "single-pulse" refers to the fact that the single-pulse radar requires for the determination of the angular position of the target just one single return pulse. In this manner, the accuracy of determination of the angular coordinate will not be affected by the amplitude of the return waves. Hence, this type of radar possesses such merits as high accuracy of measurement and resistance to interference.

There are two basic methods used in "single-pulse" determination of direction. One depends on amplitude comparison, the other, phase comparison. In the former, the antenna usually emits four slightly overlapping lobes of radiation as shown in Fig. 7-11. Azimuth angle is determined from a comparison of the amplitudes of the left and right lobes, while angle of inclination is obtained from a comparison of the upper and lower lobes. The principle involved in measuring the azimuth angle is the same as that used in measuring the angle of inclination. We will discuss only the measurement of the angle of inclination.

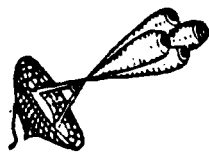


Fig. 7-11. The four lobes of radiation emitted from a single-pulse amplitude-compared radar.

The single-pulse amplitude-compared radar operates on the principle of signal comparison, as shown in Fig. 7-12. For example, suppose the target deviates

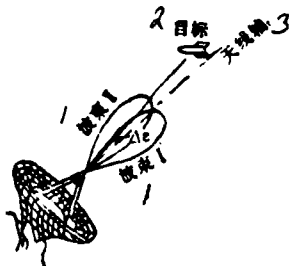


Fig. 7-12. Principle of signal comparison.
Key: (1) Beam; (2) Target; (3) Axis of antenna.

from the axis of the antenna such that Beam I gives a much stronger signal than Beam II. Then, by comparing the two signals, one can determine the angle of deviation $\Delta\epsilon$. This radar emits two beams at the same time while the common conic-scanning radar (i.e. the type usually used to track aircraft and guide artillery or surface-to-air guided missile for intercepting aircraft, as shown in Fig. 7-13) emits only one beam. The latter depends for angular position

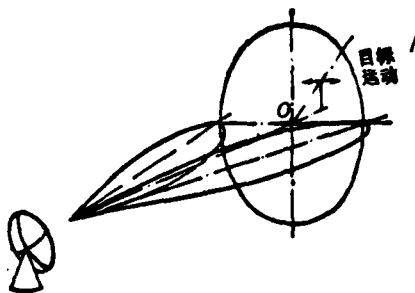


Fig. 7-13. Conic-scanning radar.
Key: (1) Target motion.

determination by signal comparison, on the receipt of several tens of return signals obtained by scanning a conic, and is thus different from the former where auto-comparison is possible.

The complexity of the shape of the surface of the invading target plus vibrations and variations in attitude during the flight cause the reflected radio waves to twinkle. (This phenomenon arises because the waves reflected from the different parts of the target interfere with one another, and the reflected signals vary as the target moves about in space.) As the method of conic-scanning entails longer measuring time, it is affected by the twinkling effect, and can only have an accuracy of 1 to 2 mils. (One mil equals 0.06 degrees.) On the other hand, the single-pulse amplitude-compared radar is not affected by the twinkling effect, and has an accuracy of approximately 0.1 mil. This is one of the advantages of this type of radar.

Following are the principles of operation for some commonly used single-pulse radars, such as the single-pulse amplitude-compared radar, the pseudo-single-pulse radar and the single-pulse phase-compared radar.

1) The single-pulse amplitude-compared radar.

The principle of operation of the single-pulse amplitude-compared radar can be illustrated with the help of Fig. 7-14. The transmitter emits two beams for measuring the angle of inclination. If these are in phase, both are designated by a "+" sign, as shown in Fig. 7-15. After the two beams are reflected from the target, they are received by the antenna, compared in the comparator and converted to the "sum" signal and "difference" signal. The "sum" signal is obtained by summing the two beams shown in Fig. 7-15(a) over all directions, resulting in the beam shown in Fig. 7-15(b). The "difference" signal is obtained by subtracting Beam II from Beam I over all directions, resulting in the beams shown in

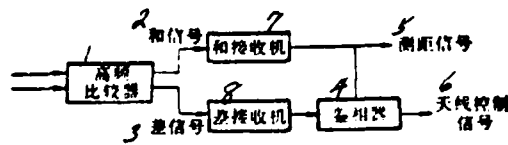


Fig. 7-14. Block diagram of the single-pulse amplitude-compared radar.

Key: (1) High-frequency comparator;
 (2) "Sum" signal; (3) "Difference" signal;
 (4) Phase meter; (5) Signal for distance measurement; (6) Signal for antenna control;
 (7) "Sum" receiver; (8) "Difference" receiver.

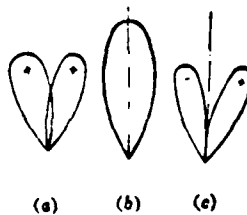


Fig. 7-15.

- (a) Two slightly overlapping beams.
 (b) Sum of the two beams.
 (c) Difference of the two beams.

Fig. 7-15(c). These two signals are amplified and processed by their respective receivers and are then compared in the phase meter. Signals for controlling the motion of the antenna are put out accordingly. When the "difference" signal is zero, the control signal is also zero, meaning that the antenna is aimed at the target. When the "difference" signal is not zero, a control signal is generated. The phase of the "sum" signal and that of the "difference" signal are compared to determine the direction the antenna axis should be pointing. The "sum" signal not only is a reference signal for measuring phase, but also is used for measuring distances because it is the sum of two beams and hence is twice as intense. This is the operating principle in the measurement of the angle of inclination.

If at the same time that the angle of inclination is measured, one also wants to measure the azimuth angle, then the left and right return beams are compared in

the high-frequency comparator, and then the "sum" signal goes to the "sum" receiver and the "difference" signal goes to a second "difference" receiver. After the signals pass through the phase meter, an azimuth control signal is generated. Thus the single-pulse amplitude-compared radar employs only one "sum" receiver and two "difference" receivers. In actual operation, the "sum" beam is obtained by adding all four beams (left, right, upper, lower) together; the "difference" beam for measuring angle of inclination is obtained by comparing the sum of the upper beam and the left and right beams with the sum of the lower beam and the left and right beams; the "difference" beam for measuring azimuth angle is obtained by comparing the sum of the left beam and the upper and lower beams with the sum of the right beam with the upper and lower beams.

2) Single-pulse phase-compared radar.

The single-pulse phase-compared radar determines the direction of the target from the return signal phase difference. The amplitude of the return signal usually has nothing to do with the target direction. The four emitted beams are usually parallel to one another, as shown in Fig. 7-16(a). The actual structure

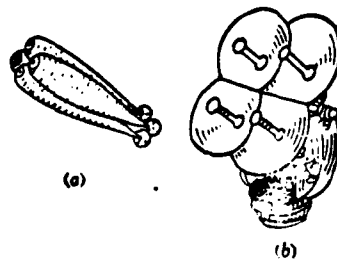


Fig. 7-16. Transmitting antenna of a single-pulse phase-compared radar.
(a) Four parallel beams
(b) Schematic diagram of the antenna.

of the antenna is as shown in Fig. 7-16(b). The antennas emitting the four beams are separate and independent from one another.

As shown in Fig. 7-17, the principle of operation of the single-pulse phase-compared radar is similar to that of determining direction (angle) from phase

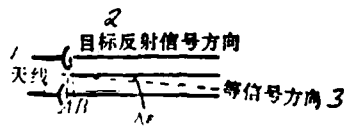


Fig. 7-17. Determination of direction from phase measurement.
Key: (1) Antenna; (2) Direction of signal reflected from target; (3) Direction of equal signals.

measurements. As the antennas all lie in the same plane, the beams are parallel, and the direction of equal signals (i.e. the direction of the antenna axes) is pointing forward. A very distant target gives nearly parallel reflected waves with nearly equal amplitudes but difference phases. The lowermost signal shown in Fig. 7-17 has traveled a distance AB further than the uppermost signal. AB is a very short distance and will not appreciably affect the signal intensity. However, it has a large effect on the phase. As the radar works in the microwave range, the wavelength is usually several centimeters. If AB is equal to one wavelength, then the difference in phase is 360° . If AB equals one-half of a wavelength, then the phase difference is 180° . The distance AB is related to the target deviation angle $\Delta\epsilon$. Hence, the deviation of the target from the antenna axis can be determined from phase measurements. The single-pulse amplitude-compared radar and the single-pulse phase-compared radar are similar in constitution. They differ only in their external appearance and in the phase meters. At present, most single-pulse radars operate in the amplitude-compared mode, although some operate in the phase-compared mode.

3) Pseudo-single-pulse radar.

The single-pulse radar requires three receivers for its operation and therefore is fairly complex in construction. A simplified version has therefore been

developed, and is named the pseudo-single-pulse radar. In this radar, the three "sum" and "difference" signals are mixed together, and only one receiver is employed. While mixing the two "difference" signals, the amplitude of the signal pulse is modulated in a manner similar to conic scanning. At the same time, a reference signal similar to conic scanning is produced, enabling the "difference" signals to be separated after amplification by the receiver. Hence, the system is also termed a latent conic scanning system to recognize the fact that it transmits signals in a way typical of the single-pulse radar but receives signals in a way similar to conic scanning. Compared to conic scanning radar, the pseudo-single-pulse radar is less susceptible to destruction by invading guided missiles or interference due to inverted phase cross-talk. However, like the conic scanning radar, it is also affected by the twinkling effect of the target-reflected signal. Thus, it cannot have a high measurement accuracy; the accuracy is generally a little over 1 mil. There are other means for converting the three-channel signal reception to one channel reception. Some systems operate on receivers. At the present time, the pseudo-single-pulse radar is more widely employed because of its simple construction.

VIII. DEFENSE PENETRATION AND ANTI-DEFENSE PENETRATION TECHNOLOGY

In ancient wars, the soldiers wore armor and fought with sabers and spears. The armor is for protection. It is a means of defense. Piercing through the armor to hurt the opponent is a type of defense penetration. Knocking off the weapon that pierces through the armor is a countermeasure against defense penetration.

The above are examples of defense, defense penetration and anti-defense penetration measures in ancient wars. Of course, armor cannot defend us against today's guided missiles. But the study of defense weapons has continued up to the present, and now we have the BMD weapon as one of the means of guided missile defense. One cannot but ask the question: Is it possible to penetrate the defense provided by the BMD weapon?

This is exactly the problem we want to discuss here, viz. the technology of defense penetration and anti-defense penetration measures.

Concepts of Defense Penetration and Anti-Defense Penetration Measures

The appearance of the ICBM was followed by the problem of how to defend against it. To every spear, there is a shield. It's only natural. Hence the development of defense penetration and anti-defense penetration technology has revolved about the development of ballistic missiles and BMD weapons.

Defense penetration refers to the penetration of the defense that the enemy has set up against offending weapons, i.e. the act of causing part or all of the defense system to be partially or totally paralyzed, thus inactivating the defense weapon (such as the BMD weapon).

Anti-defense penetration measures are measures taken against the various defense penetration tactics employed by the enemy, so that the invading weapon will

be destroyed by the defense system before it reaches the area to be attacked.

Owing to the fact that the advance-warning and interception abilities of strategic air defense systems have rapidly increased, in order to break the defense, besides increasing the number of strategic nuclear guided missiles, their range, probability of hit and survivability, one also needs to employ various means of defense penetration, such as using multi-warhead missile, letting the warhead fly tactically, etc.

A multi-warhead missile is an ICBM that carries several warheads that can individually fly toward and attack the same target or several targets. Fig. 8-1 is a schematic diagram of a warhead cluster.

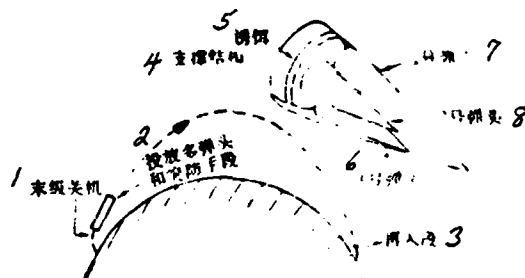


Fig. 8-1. Schematic diagram of a warhead cluster.

Key: (1) Last stage is turned off; (2) Multi-warhead structure released; other means of defense penetration employed; (3) Re-entry; (4) Structure for support; (5) Bait; (6) Warhead No. 1; (7) Warhead No. 2; (8) Warhead No. 3

Maneuverable flight of warhead refers to the ability of the invading warhead to change its original course and enter another trajectory to attack the target. There are presently two ways of changing the course of flight. One is letting the warhead rise, after being separated from the body of the missile, several tens up to one hundred kilometers, and then travel along a certain trajectory; or letting the warhead rise to an even greater altitude, gradually descend, glide a distance and then charge toward the target ballistically. The other is

having the warhead fly along the normal trajectory, enter the atmosphere and create the false phenomenon of an attack, and then suddenly turn on the engine to shift to another trajectory and attack the target. According to foreign reports, this type of maneuverable flight can enable the warhead to hit targets located several hundred kilometers beyond or on either side of the false landing point. The techniques of using warhead clusters and maneuverable flight are gradually being adopted in guided missile defense penetration.

In relation to BMD weapons, the struggle between defense penetration and anti-defense penetration measures has unfurled in many directions. Take radars for example. In order to counter warhead clusters and other defense penetration techniques, the U.S. has replaced the mechanically scanned single-pulse radar in the BMD weapon system with phased-array radars that employ electronic scanning. In the "NIKE-ZEUS" system, four independent mechanically scanned radars were employed to separately take care of target acquisition, discrimination, tracking and ABM missile guidance. The "NIKE-X," on the other hand, does not employ mechanically scanned radars that are ineffective against the warhead clusters and are highly susceptible to damage due to nuclear explosions, but uses phased radars. To increase reliability and survivability, the trend is for radar equipments not to be large and centralized but to be small and dispersed. And active research is being done on construction small multi-purpose phased-radar that are simple in construction, low-cost, and able to perform different tasks. In summary, to meet the needs of defense penetration, both the United States and the Soviet Union are making a great effort to improve the radar.

Some Defense Penetration Techniques

Many defense penetration techniques were devised as a result of the speedy development of the defense penetration technology. (See Fig. 8-2.) Two examples



Fig. 8-2. Various defense penetration techniques.

Key: (1) False target; (2) ABM missile; (3) Warhead capable of radio interference; (4) Nuclear explosion in space; (5) Warhead in maneuvered flight; (6) Small warheads released in a distributive manner.

are the penetration of the interception by the ABM missile and the active damaging or interfering with the electronic equipment in the radars of the defense system. The purpose of the former is to prevent the opponent's ABM missile from intercepting the invading warhead. The objective of the latter is to damage the functions of the radars so that they will be unable to measure such data as the distance and azimuth (azimuth angle and angle of inclination) of the true warhead.

How does one penetrate the interception by the ABM missile? Following are some techniques that are being developed or are still in a conceptual stage.

1) The use of distributive warhead cluster - A main engine and several attitude-control engines are installed in the mother warhead to correct errors arising from the flight of the guided missile, and to adjust the speed and direction of the mother warhead. In the course of flying, the mother warhead sends off the small warheads, one by one or all at once. The small warheads either attack separate targets or attack the same target along different trajectories. In the distributive warhead cluster technique, there is usually no power or control equipment on the small warheads, so that the small warheads can only fly toward the target along inertial trajectories. The small warheads can be released along the axis of the trajectory (as shown in Fig. 8-3) or in a direction

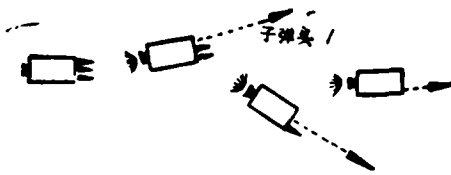


Fig. 8-3. Release of small warheads,
method 1.
(/) Small warhead.

perpendicular to it (as shown in Fig. 8-4). Thus, an interwoven net of firepower can be formed to attack the same target, or the small warheads can be released and attack the same target at different times.

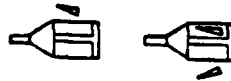


Fig. 8-4. Release of small warheads,
method 2.

2) The use of maneuverable warhead cluster - As the defense penetrating ability of the distributive multi-warhead cluster is limited, another technique is devised in which each small warhead is equipped with controls and an engine, and can engage in dynamical flight along different trajectories. The small warheads also contain homing devices that enable them to automatically aim at and hit the targets. This technique is called a maneuverable warhead cluster technique. As each small warhead is capable of flight, it is very hard for the radars of the opponent's air defense system to track and intercept all the warheads, thus making it possible for some of them to get through to the target.

3) Fortifying each small warhead so it may pass through regions containing nuclear explosions and radiations unharmed - This technique requires the manufacture of new protective materials that are radiation-resistant, and an improvement of the present guidance systems and anti-nuclear electronic equipment.

4) Choosing special trajectories (eg. very high trajectory or very low trajectory) - This is how the guided missile can avoid being detected and tracked by the radars in the defense system and then suddenly attack an important base, guided missile silo or defense region.

5) Simultaneous launching of a great number of guided missiles - The large number of targets can saturate the opponent's air defense system so that some true warheads will get through without being tracked.

Besides the above passive methods for avoiding interception, the active damaging and interfering with the opponent's defense system is also an important means for defense penetration. In order to block enemy commands, blind the radars and disable the weapons commands, various measures have to be taken to damage and interfere with the enemy's radars and other electronic systems. As mentioned above, the radar depends on return waves to determine the instantaneous position and velocity of the invading target. It then calculates the intended hit point and controls the counterattacking weapons to intercept the invading target. Based on this property of the radar, one can devise a way to interfere with the operation of the advance-warning radar. The ICBM often employs decoys made of metals, materials with metallic coating or semiconductors to fool the advance-warning radar of the BMD system.

The decoys can be released at the moment the warhead separates from the body of the missile, thus forming a cloud of interfering objects. These decoys move and tumble about along the trajectory of the warhead. In the rare atmosphere, their speeds are close to that of the warhead. The cloud of baits makes it impossible for the target-disclosing radar to discriminate between the warhead and the interfering objects (see Fig. 8-5).



Fig. 8-5. Interference by confusing the enemy.
Key: (1) Bait.

Another way to achieve interference is to use electronic jammers. One could, for example, use a rocket or a guided missile to send out electronic jammers (Fig. 8-6) that emit increased signal pulses when illuminated by the opponent's



Fig. 8-6. Interference by tricking the enemy.

radar beam just as a true warhead would. The jammers thus appear to the enemy as if they were true targets, and accomplish the mission of tricking the enemy.

Yet another method of interference is to take the initiative, attack suddenly and set off a nuclear explosion above the defense region, causing a nuclear blackout. One could also launch an anti-radar guided missile to directly attack the air defense radar and injure the operators, causing the air defense system to lose its "eyes." This type of guided missile has a small radar installed in its warhead which does not transmit signals but only receives signals from ground-based radars. It has four arms that are spiral antennas. The flight direction is automatically adjusted in accordance with the balance of energy among the four arms. The receiving radar guides the guided missile towards the enemy's radar and destroys it.

Other applicable defense penetration techniques include reducing the reflective surface area of the radar in the warhead to reduce the probability of being

discovered by the opponent's radar, or paint a layer of radiation-absorbing material on the warhead so that no return wave will get to the opponent's target radar.

Discrimination Techniques

Discrimination techniques are fundamental anti-defense penetration techniques. The discrimination system has to be able to discriminate between the true and false targets in a group of targets, i.e. to identify the true warheads by singling out the signals from invading guided missiles from among the radio interference signals from the false targets. Discrimination is a very important problem in the BMD system. In the following we will briefly discuss the fundamental principles of two discrimination techniques.

The first method is atmospheric filtering. Just as grains (rice, wheat) can be sifted with a sieve to remove sand, a swarm of targets can be "sifted" by means of the atmosphere. The dense atmosphere exerts different amounts of drag on different materials which travel at appreciably different velocities as a result. Under the action of the dense atmosphere, the targets are sorted out because of their different masses and drag (which is dependent on the density of the atmosphere and the shape, cross-section and velocity of the object). Thus the lighter targets and targets with irregular shapes (eg. shattered pieces of the last stage of a guided missile) will fall behind the true warhead. This method of using the filtering effect of the atmosphere to distinguish between the true and false targets is termed atmospheric filtering.

Atmospheric filtering is only effective for discriminating targets in the dense atmosphere. For targets outside the atmosphere, one has to employ other means for discrimination, one of which is the radar return wave technique.

The radar return wave discrimination is carried out by means of special radar. The discriminating radar tracks the target and obtains return signals. These return signals contain information related to the coordinates, velocity and reflective surface area of the target. By comparing these with those measured experimentally for known targets by means of the high-speed electronic computer, the true targets can be distinguished from the false ones.

There are several methods for carrying out radar return wave discrimination. We will discuss the one based on polarization of the radar beam. One of the actions of the target on the radar beam impinging on it is to change the polarization of the beam (i.e. the direction of the electromagnetic field). The polarization (i.e. the direction of the magnetic lines of force) of the return wave is no longer the same as that of the transmitted wave. Hence, the target may be regarded as a polarizer.

Analysis of the polarization of the return beam provides a basis for target discrimination. For convenience, we will make use of scattering matrices which have as elements the components of the polarization of the return beam. The scattering matrix expresses the relation between the target scattering properties (return beam) and the polarization of the radar beam; it also relates the ability of the radar to transmit and the ability of the radar to receive signals. Experience has shown that an object can be adequately described in terms of its shape, size, altitude, surface material and material structure. As the scattering matrix can be expressed in terms of these five factors, and each object thus has a characteristic scattering matrix, it is only natural to use scattering matrices in target discrimination.

The scattering matrix can be determined in many ways. The direct method

involves transmitting one after another two waves with orthogonal polarizations, and receiving two components of polarization for each return wave. Every time the attitude of the object changes, the radar will obtain a new set of the five parameters related to the shape, size, attitude, surface material and material structure of the object, expressed in the form of a "picture" matrix (numerical matrix). Each "picture" matrix can be regarded as a curved surface in a five-dimensional space. The "picture" matrices for the various attitudes of various known objects are stored in the computer. When the radar is tracking an unknown target, the five parameters of the unknown target is compared to the "picture" matrices of the known objects so as to identify the unknown target.

The existing target discrimination methods are still far from being perfect. Other methods are being explored. The usual approach is to first make a preliminary discrimination using some crude methods, such as discriminating targets on the basis of the properties of target motion. Experience has shown that the characteristics of target motion, reflection and radiation of energy and the interaction with the surrounding medium can all provide some basis for target discrimination (i.e. identifying the warhead from among satellites, meteorites, spaceships, etc.). The warhead can be distinguished from the false targets by measuring their reflective and radiative properties by means of the Doppler effect interferometer or high resolution optical interferometer used in disclosing target shapes.

The shock waves produced in the front and the hot gases in the wake of the flying object are also characteristics that can be used for target discrimination. The reflection and radiation of waves is also dependent on the portion of the trajectory the missile is at. In the middle section of the trajectory, the radiation is mostly in the infrared range. In the re-entry section, the warhead is

surrounded by (high temperature) heat energy and infrared radiation. The amount of energy generated while a target is decelerated by atmospheric friction is related to the mass and velocity of the target. The relationship between energy and altitude is dependent on trajectory parameters. Hence, from the characteristics of the radiation, the weight, shape and surface properties of the target can be determined. The radiative intensity is a measure of the weight of the target; the shape of the target can be obtained from frequency distribution; spectroscopic analysis gives the chemical constitution of the surface of the target. All these aid in the analysis of the target and provide a basis for target discrimination.

In order to overcome the difficulties of target discrimination, efforts are being made in all countries to devise new and more effective techniques for discrimination, such as infrared sensing, missile-carried radar discrimination and video discrimination. It has been reported that a far infrared sensing system is being developed that can measure the radiation from an invading target in the re-entry section or in part of the middle section of the trajectory. Discrimination is achieved by measuring the various target characteristics in the different wavelength ranges.

A typical target group consists of baits, metallic strips, debris of the rocket and the re-entering warhead. The far infrared sensor measures, for all the targets in the group, the "brightness" of the target in different infrared wavelength ranges. From this, one can calculate target temperature and related data. From the time dependence of "brightness," one can obtain the temperature variation of a target in the re-entry phase. As the baits, strips debris and the warhead are different in shape and size, there are definite differences in their temperature variations. Comparing the temperature variations of these targets with those measured for known objects enables one to sort and identify the unknown objects in flight.

IX. OTHER MEANS FOR INTERCEPTING GUIDED MISSILES

We have systematically exposed the reader to one of the means for intercepting ballistic guided missiles, viz. the use of an ABM missile. This intercepting system is an advanced weapon system. If one can meet the requirements of prompt detection (see Advance-Warning System), accurate discrimination (see Target Discrimination System), precise tracking (see Surface Guidance System), fast decision-making (see Command and Control System) and effective interception (see ABM Missile), then one can destroy the invading opponent - the ballistic missile.

However, in case any one of the subsystems breaks down or makes an error, then the interception operation could fail and the entire defense system could be destroyed by the enemy. Actually, the problem of target discrimination is still unsolved, and the ABM missile has a lot to be desired in its ability to accelerate fast enough and in its maneuverability. Hence, the present ABM missile is still unable to deal with invading ballistic guided missiles, and other means for interception have to be sought.

A Brief Introduction to Various Means for Interception

When people began to doubt the effectiveness of the existing BMD weapon, they asked themselves what other weapons could be devised to deal with invasions by ballistic guided missiles. This has spurred the research on other means for intercepting ballistic guided missiles. For many years, the United States and the Soviet Union have explored the various ways of interception, which include, beside the use of ABM missile to destroy the invading target, the following:

The use of lasers to intercept and destroy the invading target (mid-range,

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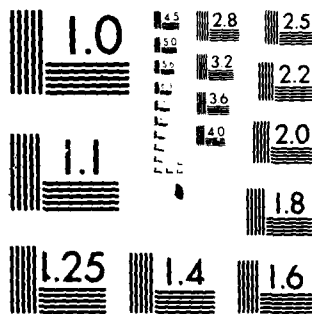
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long-range and intercontinental ballistic missiles, and airborne weapons), also called laser ballistic missile defense; the use of particle beam to intercept and destroy the invading target, also called emitted beam weapon; the use of super artillery to intercept guided missiles.

Other possibilities include the use of satellites and airborne interceptors for interception, the use of large quantities of metallic pieces to form a screen for interception, and the use of high power electromagnetic wave generators or quantum generators to inactivate the target.

Nevertheless, some of the above methods are still in the stage of research, while others are merely imaginary.

Laser Weapons

What is a laser? How does it become a weapon?

Laser (an acronym of light amplification stimulated emission) light is the light emitted when a certain substance is stimulated. It has become a new source of radiation. Laser has many applications and has great potentials when used as a weapon. This is due to the following characteristics that are typical of stimulated emissions:

- 1) Extremely small beam divergence and very high directionality - A small oil lamp can fill an entire room with light. This is because the light of the lamp is emitted in all directions, as in the case with all common light sources. Stimulated emission, however, forms a parallel beam of light that propagates in one direction only. (See Fig. 9-1.) For example, the helium-neon laser widely used in industry has, for its red stimulated light beam, a beam divergence only one-thousands of that of a search light, and a beam diameter of just a half millimeter. If a laser beam is directed toward the moon, which is over 380 thousand

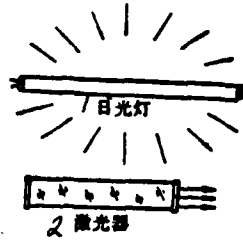


Fig. 9-1. Distinction between stimulated emission and common light.

Key: (1) Fluorescent lamp;
(2) Laser.

km away from the earth, then the beam diameter at the moon will be less than 2 km, and one can still receive the beam reflected from the moon.

2) Extremely high brightness – Because of the small beam divergence, energy is concentrated in a very small region, resulting in a very high brightness in the direction of emission. Such a high degree of concentration of energy is seen nowhere else except in nuclear explosions.

3) High monochromaticity – Monochromatic light is light with wavelengths restricted to a very small range. The range of wavelength is called the linewidth. The narrower the linewidth, the purer the light, and the better the monochromaticity.

Every color of light has a definite wavelength. The light emitted from common light sources contains many different wavelengths. In other words, they cover large wavelength ranges. For example, the light emitted from the sun contains red, orange, yellow, green, blue, indigo, and violet light, and radiation of other wavelengths.

Man has utilized the above characteristics of stimulated emission for the benefit of the human race. He is also using stimulated emission as a weapon in wars.

Can stimulated light be produced naturally? No. It can only be emitted by a laser. There are many types of lasers. Basically, they all consist of three parts - excitation source, lasing material and optical cavity for oscillation, as shown in Fig. 9-2.

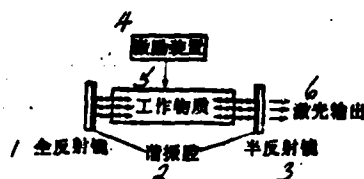


Fig. 9-2. Laser structures.
Key: (1) Mirror; (2) Cavity for oscillation; (3) Half-mirror; (4) Excitation device; (5) Lasing material; (6) Laser output.

The excitation source is a device that imparts energy to the laser by means of optical excitation, gaseous discharge or electrical excitation.

The lasing material is the working material that can emit stimulated light. Hundreds of materials have been found that can be used as lasing material, eg. crystals, glass, gases, semiconductors, organic dyes, etc. Lasers made from crystals or glasses are termed solid-state lasers, one example being the chromium-doped ruby laser. Gaseous layers employ gases as working material. Examples include the helium-neon laser and the carbon-dioxide laser. Lasers employing semiconducting materials are called semiconductor lasers. An example is the gallium arsenide laser.

As the excited particles (such as electrons, protons, molecules and ions) in a material will independently and spontaneously emit light, such emission is uncontrolled. Such random emission results in incoherent light that is given off in all directions. This process is predominant in common light sources. Another process is possible in the emission of light from materials. Under the illumination of a certain wavelength of light, the excited particle can emit

light of the same wavelength that travels in the same direction and is in phase with the incident beam. This is called stimulated emission. Stimulated emission can be controlled by controlling the incident beam. If we compare the random emission of common light sources to a disorderly group of people, then stimulated emission can be likened to a column of soldiers walking in step.

Certain substances (lasing materials) when excited by a strong excitation source can be brought into a state of "inversion." (In common substances, the number of atoms in the lower state is usually larger than the number of atoms in the higher state. Inversion is achieved when the number of atoms in the higher state becomes greater than the number of atoms in the lower state, as shown in Figs. 9-3 and 9-3.) Under these conditions, the stimulated emission is

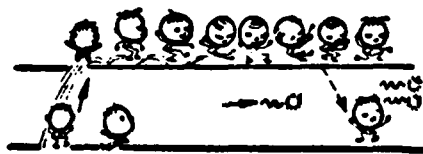


Fig. 9-3. State of "particle inversion."

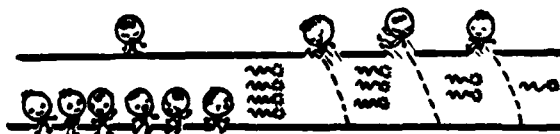


Fig. 9-4. Normal state where most particles are in the lowest energy state.

augmented and eventually becomes the predominant radiation. Thus it becomes possible to control the radiation by means of an optical cavity. The cavity formed by two mirrors has a selective effect on the wavelength and direction of propagation of the radiation. It only permits light of certain wavelengths and direction of propagation to exist in it, i.e., it supports only certain "modes" of radiation. If a lasing material is placed in an optical cavity and has been pumped to an inverted state by an excitation source, then the emitted radiation

will be in the mode or modes selected by the optical cavity, and put out at one end of the optical cavity. This will be the desired laser light.

Experiments show that if a laser light beam is focused onto an object, that object will instantly burn to ashes. If one aims a laser beam at the enemy, then one could destroy him without using a single bullet. What a remarkable weapon!

What is a laser weapon? Stated simply, it is a weapon that utilizes laser beams to cause damage to enemy soldiers, cities or military establishments. A high power laser equipped with relay stations that help direct the light onto the target and tracking and aiming systems becomes a weapon that can be used in actual combats. There are other military applications of the laser light, such as laser-guided bombs or cannon balls, laser radars, laser distance measurements, laser gyroscopes and laser communications.

A laser weapon usually consists of a high power laser, target tacking guidance system, command and control system and power supply, as shown in Figs. 9-5 and 9-6.

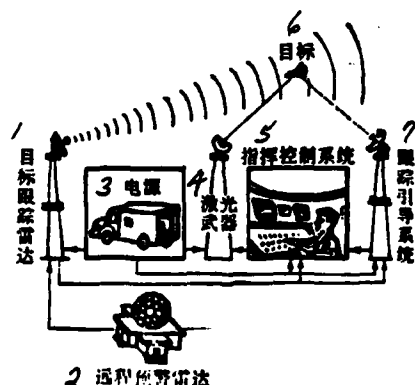


Fig. 9-5. The main constituents of a laser weapon.

Key: (1) Target tracking radar;
(2) Perimeter advance-warning radar;
(3) Power Supply; (4) Laser weapon.
(5) Command and control system;
(6) Target; (7) Tracking guidance system

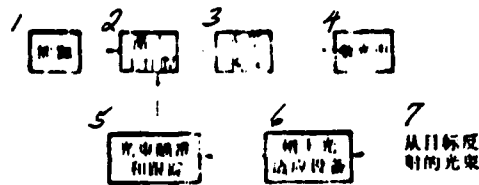


Fig. 9-6. Block diagram of a laser weapon.

Key: (1) Power supply; (2) Optical cavity; (3) Optical equipment; (4) Laser beam; (5) Beam aiming and tracking; (6) Interferometer; (7) Beam reflected from target.

The high-power laser is a fundamental constituent of the laser weapon. Of the hundreds of kinds of lasers, the ones used in weapon systems are mainly gaseous lasers, electrically excited lasers and chemical lasers. Chemical lasers are the most advanced among these.

In using laser weapons, only when the light is focused on the target will the energy be effectively concentrated to destroy the target (e.g. melt the surface of the target, damage the structures, ignite the combustible materials, burn living creatures and men to ashes, etc.). Thus it is important to have a tracking and guidance system to accurately track the target and guide the laser beam.

The target tracking system accurately determines the position and velocity of the target and ensures that the target will not get away. The guidance system directs the laser beam to the target to hit it by the square. If the energy of the laser beam is delivered along the direction of aim of the tracking device, then that direction is the guidance direction of the laser beam.

To deal with high-speed flying targets (eg. warhead of guided missile, airborne weapons), it is necessary to calculate in advance the hit point. Inaccuracy in the calculation of the hit point is one of the main reasons for the

defense weapon to miss the target. The problem becomes even more pronounced when the target is one that can engage in tactical flight. If the relay of energy is accomplished via mirrors in a fast and accurate manner, the accuracy of guidance of the aiming system is ensured, and the limiting factor in the accuracy of guidance lies only in the accuracy in the calculation of the hit point. The accuracy of tracking of an airborne laser is presently several ten thousandths of a degree.

There are many advantages in using laser weapons for interception:

- 1) Laser light travels at the speed of light and can thus destroy the invading guided missile or flying object almost instantaneously. In other words, it is not necessary to allow for the extra time it takes for an ordinary weapon to reach the target.

Taking the average speed of the ABM missile to be 4 km/sec, the laser beam travels about 75,000 times as fast. The distance traversed by the laser beam in one second will take the ABM missile nearly 21 hours (almost one whole day) to cover. These figures are truly amazing.

If the laser and the ABM missile (traveling at an average velocity of 4 km/sec) are placed at the same location and are used to hit the same target 1,000 km away, it takes the laser zero time to complete the task while the ABM missile does not hit the target until four minutes later. This is to say that the laser can provide the system with four more minutes of time for tracking and discrimination. These few minutes are very precious to a defense weapon.

- 2) Laser has high power, high focusability, and hence imparts high destructive power to the weapon system. If the light is focused with a lens, the actual temperature at the focus can be as high as several thousand degrees. You can do a simple experiment by placing a convex lens above a piece of paper in the sunlight. You will soon find out that a hole is burned in the paper. If we use the

convex lens to focus the high-power laser beam, then it would not be surprising if the focused beam burns a hard object into ashes.

3) The laser has little inertia and is very flexible. The direction can be changed at any time to attack any target, resulting in a high rate of damage.

4) Non-nuclear damages caused by the laser do not pollute the surface and space with radiation. After a nuclear weapon explodes, besides causing damage through the shock waves and intense heat, it also produces radiative pollution that injures people and livestock. For example, in 1945, many innocent people in Hiroshima, Japan, were mutilated by the first atomic bomb.

Stated simply, the laser weapon has great firepower, can select targets speedily, can hit targets traveling at high speeds, and is not susceptible to electronic interference.

Yet, there are two sides to every matter. There are still a few technical problems that need to be solved for the laser weapon. At the present time, the laser has relatively low power. Hence, it is necessary to increase the power of the laser. Accuracy of guidance should also be increased to make the laser weapon more nearly perfect. Since only when the laser beam is focused at the target will the optical energy be concentrated enough to destroy it, a stringent requirement is placed on the guidance of the light beam. At present, only the highly accurate video tracking system can meet the requirement on accuracy of measurements. However, it cannot be operated under all weather conditions. Hence, the problem of tracking and aiming must also be solved. The atmosphere attenuates the laser beam seriously, and attention should also be directed to this problem.

If the laser is carried by an earth satellite or a spaceship, it is called a satellite-carried laser. This laser can intercept ballistic guided missiles and attack airborne weapons. It is an ideal weapon because the empty space is especially suitable for long-distance propagation of the laser beam. There will be no atmospheric attenuation to affect the effectiveness of the laser weapon.

Fig. 9-7 is a schematic diagram of how a laser weapon destroys the target.



Fig. 9-7. Target destruction by laser weapon.

Key: (1) Destroying the ballistic guided missile from air; (2) Trajectory of ballistic guided missile; (3) Destroying the ballistic guided missile from surface.

With the speedy progress of laser technology, it is to be expected that the laser power will be increased, and hence the development of laser weapons will have an even greater future. As the defense penetration technology is developing very fast, it has become very hard for the BMD weapon system to keep up with.

Under these conditions, the laser weapon may become a new means for intercepting ballistic missiles. In other words, using laser weapons (in the air or on the surface) to intercept ballistic missiles is an ideal means for anti-guided missile defense, and is an important direction laser weapons development is taking. It has been reported that the U.S. Department of Defense has successfully completed an experiment in which an anti-tank guided missile was hit down by means of a laser weapon. There seems to be a great future for laser weapons.

Particle Beam Weapons

The particle beam weapon is a type of weapon which destroys the target by means of a beam of high-energy particles which have been accelerated in high-energy accelerator.

The particles coming out of the high-energy accelerator include electrons, protons and neutral atoms. The first two types of particles are charged particles while the third is not charged. (These neutral atoms are obtained from charged atoms that lose their charges while passing through the accelerator.)

We will use charged particle beams to illustrate the constitution of particle beam weapons. The particle beam weapon is made up of three main parts, viz. energy source, electron nozzle and beam accelerator.

The large amount of energy required cannot be supplied by any electric power plant but comes from the pulsed power generated from nuclear fissions or nuclear fusions. A special type of nuclear generator has been designed that can generate 100 to 1,000 pulses per second. Vast amounts of energy derived from nuclear fissions or fusions are put out in the form of high voltage pulsed currents, which pass through the control switches and special circuits and are instantaneously fed into a giant energy storage. The charges are accumulated and then

discharged via an ultra-high voltage switch within a time on the order of nano-seconds.

The flow comparison device and the electron injector convert the high voltage pulses into an electron beam. The electron beam is accelerated by strong electromagnetic fields in the long electron gun and is shot out onto the beam accelerator via the electron nozzle, ready to be used as a medium for forming and accelerating protons.

The beam accelerator is the most essential part of the particle beam weapon. The working substance (eg. hydrogen) is introduced through an inlet located between the electron nozzle and the beam accelerator. The collision of the high-energy electrons with the working material knocks electrons off the latter, forming protons which are collectively accelerated and eventually emitted at a velocity close to that of light to destroy the target. The basic structures of a particle beam weapon are shown in Fig. 9-8.

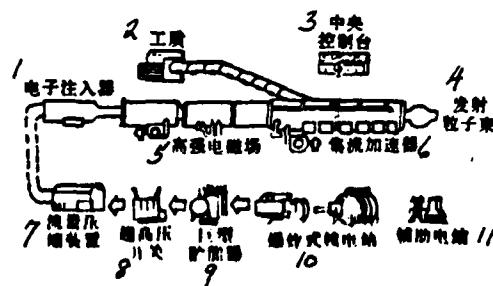


Fig. 9-8. Schematic diagram of a particle beam weapon.

Key: (1) Electron injector; (2) Working substance; (3) Central control unit; (4) Emission of particle beam; (5) Strong electromagnetic field; (6) Beam accelerator; (7) Flow compression device; (8) Ultra-high voltage switch; (9) Giant energy storage; (10) Explosive type nuclear power station; (11) Auxiliary power station.

Before the particle beam is emitted, it is passed through a magnetic deflector so that the negatively charged electrons are expelled through an opening.

The entire process is carried out in a magnetic field in a closed system under high vacuum so that the particle beam can undergo directed acceleration.

This is how a particle beam weapon operates in combat: Nuclear fission or fusion causes explosive-type or pulsed generation of electricity to produce high-power pulsed charged particle beam. The particle beam strikes the invading target, from surface or space, at a speed close to the speed of light. It can burn through the body of the target, activate the fuze system in the nuclear warhead and damage its electronic equipment, so that the invading guided missile will be destroyed or become ineffective before it reaches the region to be attacked. Some people liken the destructive action of the particle beam weapon to that of lightning striking a tree. The operation of the particle beam weapon is illustrated with the block diagram in Fig. 9-9.

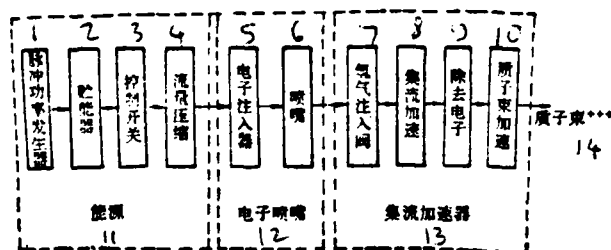


Fig. 9-9. Particle beam flow chart.
Key: (1) Pulsed power generator; (2) Energy shortage; (3) Control switch; (4) Flow compressions; (5) Electron injector; (6) Nozzle; (7) Hydrogen gas inlet; (8) Beam acceleration; (9) Electron removal; (10) Proton beam acceleration; (11) Energy source; (12) Electron nozzle; (13) Beam acceleration; (14) Proton beam.

The particle beam weapon has many merits. For example:

1) Speedy destruction of target — The particle beam is shot out at a very high speed (300 km/sec) while the ABM missile has an average speed of only three to four km/sec — more than a hundred thousand times slower than the former. To intercept a target 1,000 km away, it will only take the particle beam an instant

while it will take the ABM missile a few seconds to a few minutes (6.5 seconds for "SPRINT" and 6 minutes for "SPARTAN").

2) High probability of hit and large destructive power - The particle beam hits the target directly. It can be aimed at the target repeatedly until it hits the target, and is therefore different from the regular weapons, where a warhead or cannonball is delivered at the vicinity of the target to explode there.

3) Flexibility - The direction of the beam can be changed at will to hit targets coming from any direction.

4) No accompanying problem of nuclear pollution.

The particle beam is similar to the laser beam in many respects, such as linear propagation in a fixed direction, high speed, high accuracy, high energy (the usual requirement is 10^9 - 10^{12} Joules/pulse), and the ability to be used repeatedly. Therefore, the particle beam and laser weapons are given the general name "directional weapons." Of course, the laser beam is attenuated by clouds, while the particle beam, like lightning, is not affected by weather conditions. Hence, the latter is also referred to as an "all-weather" weapon.

Like any other weapon, the particle beam weapon requires the target to be accurately tracked and aimed at. Hence, it is necessary to have a highly accurate system for determining target position and tracking the target, so that the particle beam may be directed to the target. The influence of magnetic fields is one of the causes for the deviation of the particle beam from its original direction. This results in inaccuracies in tracking and aiming. If the beam has deviated from the target, the beam has to be brought back by means of a device that can modify the direction of the beam. "Magnetic mirror" is one such device. It can vary the direction of the beam by varying the

strength of the magnet in the device, and operates in much the same way as a mirror would reflect light. The magnetic mirror enables the beam direction to be changed at any time to aim accurately at the target. The particle beam weapon also needs to have a system for evaluating the damage done. If the first hit has missed, then the deviation of the beam from the target has to be determined and used as a basis for adjusting the beam direction for the next attempt.

An example of a type of charged particle beam in conception is a negatively charged hydrogen particle beam that is produced in the following manner. Hydrogen gas is introduced at one end of the electron beam generator. The electron beam ionizes the hydrogen atoms to form protons. The large-mass, high-speed (traveling at a speed close to that of light) protons are accelerated to become a negatively charged particle beam. Fig. 9-10 is a schematic diagram of a particle beam directed toward a target from the ground, while Fig. 9-11 shows a particle beam that is aimed at a target from a base in space.

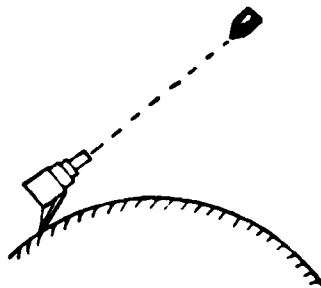


Fig. 9-10. Ground-based particle beam weapon.

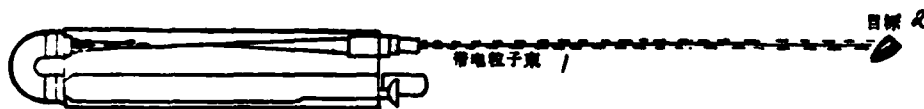


Fig. 9-11. Particle beam operated in space.
Key: (1) Charged particle beam; (2) Target.

Analysis and experiments on the propagation and stability of the particle beam have shown that neutral particle beams are more suitable for use outside the atmosphere where the beam will not be attenuated by the atmosphere or affected by the earth's magnetic field. On the other hand, charged particle beams are more suitable for use in the atmosphere.

It has been estimated that the particle beam weapon is required to have an energy of the order of 10^{12} Joules in each pulse, and a pulsewidth of about one msec. As the beam is directly aimed at the target, it is an effective means for antimissile defense. Since the particles move at a speed close to that of light, no allowance needs to be made for the shooting time. The beam can be swiftly switched from one target to another and is able to deal with multi-warhead missiles. Hence, the particle beam weapon is also an ideal weapon that man has conceived. Compared to the ABM missile, it is faster, has higher accuracy and can much better handle multi-warhead missiles and maneuverable missiles.

Although the particle beam and the laser are both directional weapons, they are different. The former uses particles while the latter uses photons to hit the target. Laser beam is an organized collection of light quanta (photons). Particle beam is a collection of charged or neutral particles emitted from a high-energy accelerator. There are many ways for producing particles. An example is an explosion of a hydrogen bomb.

Over ten years of research has shown that the particle beam has a great potential as an anti-ballistic missile weapon. Even though it is still far from meeting the requirements of practical usage, it is being intensively studied abroad and regarded as very important.

Fig. 9-12 shows an imagery system which can intercept the guided missile by various means.

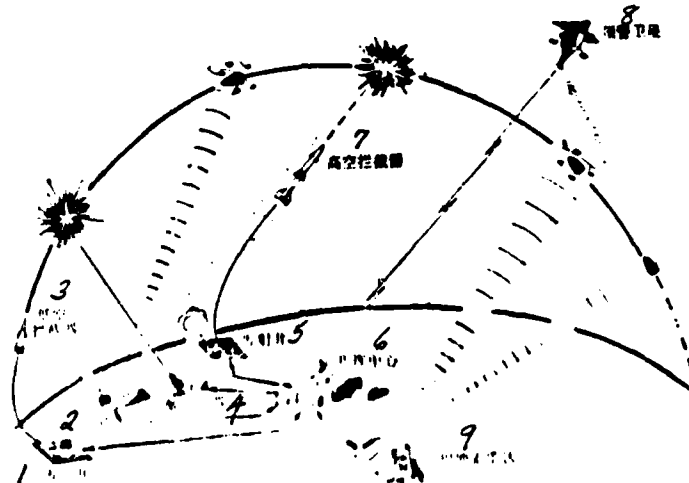


Fig. 9-12. An imagery system in which guided missile interception is achieved by various means.
Key: (1) Launch site; (2) Radar; (3) Low-altitude interception; (4) Laser weapon; (5) Launch site; (6) Command center; (7) High-altitude interceptor; (8) Advance-warning satellite; (9) Perimeter acquisition radar.

X. PRESENT STATUS AND FUTURE PROSPECTS OF FOREIGN BMD WEAPONS

There was once a man who sold spears and shields. He boasted of his shields, "Nothing can pierce through them." After awhile, he said of his spears, "These sharp spears can pierce through anything." When asked, "How about using your spear to pierce your shield?" he was at a loss how to answer.

This parable, taken from the book Han Fei Tzu, is a simple illustration of the relationship between the spear and the shield. Even the most advanced weapons are really nothing but extensions of the development of shields and spears. The ballistic missile is, for example, a kind of modern spear, and the BMD weapon is a kind of modern shield.

Maybe you will ask, "How about using a modern spear (guided missile) to pierce a modern shield (BMD weapon)?"

Nobody can answer this question correctly at present. Shields and spears have always helped each other's development. Electronic jamming and anti-jamming have complemented and spurred each other's development and production, so have the defense penetration and anti-defense penetration systems.

U.S. BMD Weapons

At the same time that the U.S. and the Soviet Union are actively developing various types of offensive guided missiles, they are also enthusiastically developing the corresponding defensive weapons.

The U.S. has engaged in the development of BMD weapon systems since 1955. A simple flow-chart shows the different stages of development:



The "NIKE-ZEUS" BMD system was developed by the U.S. Army using the surface-to-air guided missile as a basis. The system employs two kinds of interceptors. One of these is a three-stage solid-propellant guided missile used for defending against ICBM invasion. Its total length is 14.63 m; the maximum diameter is 0.91 m; it weighs 10.3 tons and has less than two minutes of operating time. The other kind is a two-stage solid-propellant guided missile used for intercepting airplanes. It is made up of the second and third stages of the first kind of interceptor, and is 8.23 m long.

The third stage of the "NIKE-ZEUS" ABM missile is mainly used for controlling the motion of the ABM missile. It is equipped with two types of controls. One operates on aerodynamics, and is used in the atmosphere; the other operates on thrust, and is used outside the atmosphere.

The "NIKE-ZEUS" intercepts the invading guided missile in the last section of its trajectory, at an altitude of 110-160 km. The system is made up of the following parts:

- 1) "NIKE-ZEUS" ABM missile
- 2) Target acquisition radar, effective over a distance of 1,600 km
- 3) Target discriminating radar, effective over a distance of 960 km
- 4) Target tracking radar, effective over a distance of 320 km
- 5) Data-processing computer
- 6) ABM missile guidance radar, effective over a distance of 320 km
- 7) ABM missile guidance computer, capable of guiding one to three ABM missiles to intercept the target.

The appearance of the "NIKE-ZEUS" necessitated the use of vast amounts of light-weight baits (false targets) which made "NIKE-ZEUS" ineffective in actual combat.

Why did the first generation of BMD weapons of the United States lose its effectiveness in combat? And how does the second generation of BMD weapon look?

The fact is that the appearance of a swarm of baits accompanying the true warhead had exposed the fatal weakness of "NIKE-ZEUS" - not being able to discriminate the true targets from the false ones. It was also found out gradually that the "NIKE-ZEUS" had other technical deficiencies such as limited capacity (i.e. the radar was incapable of dealing with many targets) and limited speed of the mechanically scanned radar. Hence, the "NIKE-ZEUS" program was cancelled in 1964. This marked the end of the first generation of U.S. BMD system.

The design of the second generation of BMD systems was focused on overcoming the weaknesses of the "NIKE-ZEUS."

The "NIKE-X" consists of the following fundamental parts:

- 1) "SPRINT"
- 2) "SPARTAN"
- 3) Target acquisition radar
- 4) Missile site radar (MSR)
- 5) High-speed computer.

The design of the "SPRINT" low-altitude interceptor was for the purpose of solving the problem of target discrimination. Remember that atmospheric filtering is effective only for altitudes below 60-80 km.

"SPRINT" is a highly accelerated interceptor, with acceleration reading 100 g. (The acceleration of a freely falling body is 5, i.e. 9.80 m/sec^2 .)

The "SPARTAN" was designed for increased range. It carries a heavier nuclear warhead of higher TNT-equivalent. Thus, it can intercept invading targets at higher altitudes.

The "NIKE-X" is made up of the "SPRINT" and the "SPARTAN" which intercept targets in a two-step manner. The invading target is first intercepted by the "SPARTAN" at a high altitude. The targets that escape the first interception will be intercepted by the "SPRINT" at a lower altitude.

Another important part of "NIKE-X" is the multi-functional phased-array radar. As this radar is the answer to the problem of many-target tracking, it is used in target acquisition radars and missile site radars.

Based on "NIKE-X," improvements were made to increase defense capability. The range of "SPARTAN" was increased. Far-infrared guidance was adopted to enable the "SPARTAN" to deal with multi-warhead missile, distributive re-entering warheads, maneuverable warheads, low-trajectory guided missile and partial-trajectory weapons. The "SPRINT" was modified to have higher acceleration, higher speed, better mobility and higher guidance accuracy. To solve the problem of discrimination, the multi-functional phased-array radar was designed and fabricated.

"NIKE-X" had gone one step further than the "NIKE-ZEUS" system by adopting two-step (high- and low-altitude) interception. However, it was not deployed. When our country successfully exploded the hydrogen bomb in 1967, the U.S. government was very much shocked. Therefore, based on the design of "NIKE-X," another simpler system of lower capability for defense was set up and given the name "SENTINEL."

In order to be able to deal with the Soviets, the U.S. did not stop the development of BMD systems with the "SENTINEL." In March, 1969 the U.S. stopped the production and deployment of the "SENTINEL," and started the fabrication of the "SAFEGUARD" BMD system. Fig. 10-1 shows the evolution of the "SAFEGUARD."

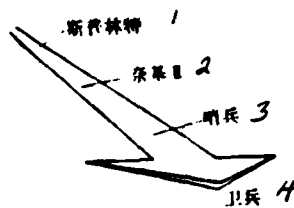


Fig. 10-1. Evolution of the "SAFEGUARD"
Key: (1) "SPRINT" (2) "NIKE-X" (3) "SENTINEL"
(4) "SAFEGUARD."

The basic constitution of the "SAFEGUARD" is the same as that of the "SENTINEL." Both are made up of the perimeter acquisition radar, ABM missile site radars, high-altitude interceptor "SPARTAN," low-altitude interceptor "SPRINT" and data processing system. (See Fig. 10-2.)

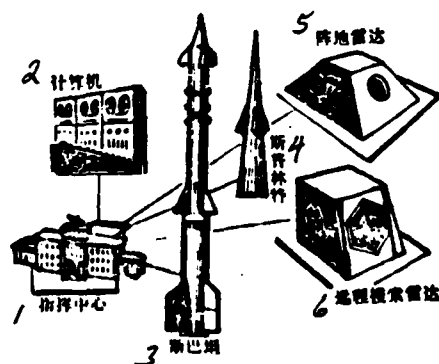


Fig. 10-2. Main constituent parts of the "SAFEGUARD" system.
Key: (1) Command center; (2) Computer;
(3) "SPARTAN" (4) "SPRINT" (5) Missile
site radar; (6) Perimeter acquisition
radar.

The perimeter acquisition radar (PAR) is used in long-range searching and warning, discrimination and tracking. It is deployed in the northern part of the United States and is installed in reinforced concrete structures 61 m² and 33.5 m high. The total surface area occupied by the radar is 1,210,000 m². It has only one array surface, circular in shape, with diameter approximately 40 m, and consisting of over 6,200 electronically scanned antennas. The radar is effective over a distance greater than 3,200 km.

The ABM missile site radar (MSR) is used to guide the "SPARTAN" and the "SPRINT" to intercept the target. It can also be used to accurately determine the trajectory data of targets at a close distance. The MSR is effective up to a distance of about 1,300 km. It has a definite ability to discriminate, and can track several targets at the same time.

To meet the demands of actual combat, the "SAFEGUARD" incorporated a communications and logistics system which is connected to the other five parts, and transmits data and information at a high speed among them.

Still, the "SAFEGUARD" had only limited effectiveness. It required three "SPRINT" low-altitude interceptors to intercept one target. It has low capability for discrimination; at high altitudes its ability to discriminate is almost zero. When the invading target releases vast amounts of light-weight baits such as metallic strips distributed in a region tens or a hundred times the size of the true warhead, the radar will not be able to discriminate the true target from the false ones hiding it. This is a big disadvantage to the "SAFEGUARD." The radar is bulky and occupies a large surface area, thus susceptible to damage by nuclear attack. The "SAFEGUARD" had low reliability. In combat there will be thousands of commands that need to be transmitted at a high speed, automatically. In case anything goes wrong in this huge and complicated system, the entire system will become ineffective to ward off enemy attack. Moreover, there are other technical problems. As a result, the "SAFEGUARD" was closed down in February, 1976 save the perimeter acquisition radar.

This marked the end of the only U.S. BMD system deployed in Grand Forks, North Dakota, in the vicinity of an ICBM launch site.

The 21 years (from 1955 to 1976) of U.S. BMD system development can be summarized as follows.

The "NIKE-ZEUS" program lasted 11 years. Total investment was \$1,300 million. Experience in BMD system was accumulated.

On the basis of the "NIKE-ZEUS" system, "NIKE-X" and "SENTINEL" and finally "SAFEGUARD" were developed. Although the "SAFEGUARD" was deployed, it was eventually closed down because of insufficient effectiveness.

To solve the various technical difficulties in BMD systems, the U.S. started a series of research on discrimination, radar, infrared and laser technology.

The total investment for these 21 years was over \$11,674,000,000 with an average of about \$500 million per year.

In addition, the U.S. is continuing its efforts in exploring new methods by doing research on laser weapons and particle beam weapons.

Soviet BMD Weapons

At the same time that the Soviet was actively developing offensive weapons, the defense weapons received equal attention. According to foreign reports, the Soviet started the development of BMD systems at about the same time that the U.S. did. In 1964, there appeared in Moscow the so-called "RUBBER BOOT" ABM missile.

The BMD system developed in 1969 consisted of:

- 1) The ABM missile ("RUBBER BOOT")
- 2) Target tracking radar
- 3) ABM missile trajectory radar

- 4) Perimeter acquisition and tracking radar (referred to as "DOG DEN" in the West)
- 5) Advance-warning radar (referred to as "PIGEON CAGE" in the West).

These major components were deployed around Moscow except for the advance-warning radars which were set up on the border.

The "RUBBER BOOT" is a two-stage or three-stage solid-propellant guided missile that intercepts at an altitude of 320 km and employs nuclear warhead.

The perimeter acquisition and tracking radar can track a guided missile about 2,800 km away and is capable of preliminary discrimination.

The advance-warning radar is a phased-array radar. It can discover an invading target when it is about 5,900 km away. It transmits the original target information to the perimeter acquisition and tracking radar near Moscow.

The site radars (i.e. target tracking radar and ABM missile tracking radar) undertakes final tracking and discrimination, based on information transmitted from the perimeter acquisition and tracking radar. It also guides the ABM missile to intercept the target.

The radar network of the Soviet BMD weapon system is as shown in Fig. 10-3.

The Soviets spent several years in setting up 64 ABM missile launch sites, divided into four combat units. Each unit has 16 launch sites and two radar sites. Each radar site is equipped with one large-size target tracking radar and two smaller tracking guidance radars. The large-size radar can track about eight targets and is used in interceptions external to the atmosphere. According to analyses made abroad, the "RUBBER BOOT" system is similar to the U.S. "NIKE-ZEUS" system.

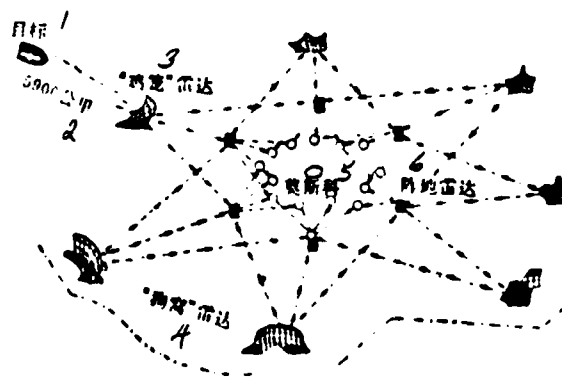


Fig. 10-3. Radar network in Soviet BMD system.
Key: (1) Target; (2) 5,900 km; (3) "PIGEON CAGE" radar; (4) "DOG DEN" radar; (5) Moscow; (6) Site radar.

In competition with the U.S. the Soviets stepped up the development of the BMD system. According to foreign sources, the Soviets are also working on a two-step interception system similar to the "SPARTINA" and the "SPUTNIK." Furthermore, the Soviets have intensified the research on laser weapons and particle beam weapons. She is leading the U.S. in particle beam weaponry.

An Outlook on BMD Weapons

The Soviets and the U.S. have used great manpower and resources over the past twenty plus years to develop an extremely huge, complex and expensive BMD weapon system so as to defend themselves against a sudden attack by ballistic missiles (such as those launched from the ground or from submarines). They seem to have derived a feeling of security from the "Great Wall" that they have built. The problem, however, is not that simple.

Many defense penetration techniques have been adopted to aid the ballistic guided missile to break through the defense provided by the BMD system. Some examples are the use of baits, jammers, distributive warhead clusters and tactical warhead clusters.

Is the BMD system totally helpless in case of attack by guided missiles in disguise? No.

The defense could employ simultaneously various different means for interception, such as the ABM interceptor, laser and particle beam.

There are still some unsolved technical problems of the BMD system. The system has low capability for discrimination. It cannot effectively intercept many targets or maneuverable warhead clusters. Its radars are susceptible to damage by nuclear explosions. The interceptors have limited maneuverability and it is difficult for them to deal with maneuverable targets. Hence, the governments abroad are placing great importance on research on these problems, hoping that they may thus form advanced weapon systems.

Regarding interceptors, propellants with super-high combustion rates are being developed; high-strength missile body and electronic devices that can withstand high accelerations will be able to improve the intercepting capability. It has also been conceived to develop a three-step interception process in which the high-altitude interceptor will be able to intercept targets at an even higher altitude (larger target distance) while the low-altitude interceptor will take care of targets at even lower altitudes (below 9 km). The high-altitude interceptor will contain an auxiliary guidance system and have improved ability for discrimination. The low-altitude interceptor will be improved in maneuverability and speed. The second-step of the interception process takes place at an altitude of 9-45 km, and is called trajectory end-section defense.

With respect to performance of the system, new technologies are being applied. Small-sized maneuverable radars and computer systems that are made up of smaller

subsystems will be adopted; discrimination techniques will be improved by developing electro-optical detection techniques.

In the future, the battlefield will move from land, sea and sky to space, and war will become "four-dimensional." One way to defend ourselves in such warfare will be to use satellites for searching, tracking, discriminating, and intercepting the invading targets. Interception could be accomplished by a "satellite BMD system" in which the satellite carries an interceptor for intercepting guided missiles.

As regards laser weapons, it has already been successfully used abroad to intercept a high-speed anti-tank guided missile. As the laser weapon has a high probability of hitting the target and can destroy the target instantly, it is sure to become an effective means for intercepting invading guided missiles.

As for the particle beam weapon, the U.S. and the Soviets are exploring and experimenting to make it a useful weapon.

In summary, there are still some unsolved technical problems in the BMD weapon system, such as target discrimination, reliability, ability to intercept many targets or maneuverable targets, resistance to nuclear explosions, etc. Hence, the entire system is still in a stage of research and experimentation and has not yet become a practical, effective defense weapon. What will be the best means for defense to be used in the future BMD system— laser, particle beam or others? This is a question that many countries are trying to find the answer to. However, one can predict that the laser weapon is a very hopeful candidate.

TABLES

Table 1. Characteristics of the trajectories of ballistic missiles.

1 弹道导弹种类	2 射程 (公里)	3 高度 (公里)	4 最大速度 (马赫)	5 飞行时间 (分钟)
2 中 程	1600	375	3690	10.7
	3200	690	5000	15.9
	4800	915	5800	20.9
3 远 程	8000	1120	6150	25.3
	9600	12700	6810	29.0
	10200	1320	7400	35.2
	12000	1410	7700	37.4

Key: (1) Type of ballistic missile; (2) Mid-range; (3) ICBM; (4) Range of trajectory; (5) Altitude; (6) Maximum velocity; (7) Time of flight; (8) km; (9) m/sec; (10) min.

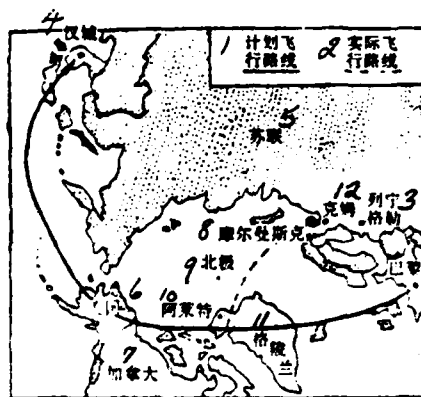
Table 2. Subdivision of the Radio Waves

Wavelength		Wavelength Range	Frequency Range
Long Waves		20,000 - 3,000 m	15 - 100 Hz
Intermediate Waves	Long Intermediate Waves	3,000 - 2,000 m	100 - 150 KHz
	Short Intermediate Waves	2,000 - 200 m	150 - 1,500 KHz
Short Waves		200 - 10 m	1.5 - 30 MHz
Ultrashort Waves		10 - 1 m	30 - 3,000 MHz
Microwaves	Decimeter Waves	1 m - 10 cm	300 - 3,000 MHz
	Centimeter Waves	10 - 1 cm	3,000 - 30,000 MHz
	Millimeter Waves	10 - 1 mm	30,000 - 300,000 MHz
	Submillimeter Waves	Shorter than 1 mm	Over 30,000 MHz

Table 3. Characteristic Parameters of U.S. BMD Weapons

Name	NIKE-ZEUS	SPRINT	SPARTAN
Range (km)	320	60	640
Velocity (km/sec)	2.8	3.0	3.5
Altitude (km)	160	Below 50	300
Weight at launching (ton)	10.4	3.4	15
Length (m)	14.6	8.2	16.6
Diameter (m)	0.9	1.37	1.1
Engine	3 solid-propellant engines	2 solid-propellant engines	3 solid-propellant engines
No. of stages	3	2	3
Guidance system	Radio command	Radio command	Radio command
Warhead (TNT-equivalent)	Nuclear	Nuclear (1,000 tons)	Nuclear (several million tons)
Remark		Low-altitude interceptor	High-altitude interceptor

APPENDED FIGURE



Course of flight of Airliner Flight No. 902.
 Key: (1) Planned course of flight; (2) Actual course of flight; (3) Leningrad; (4) Seoul; (5) USSR; (6) United States of America; (7) Canada; (8) Murmansk; (9) North Pole; (10) Ellesmere; (11) Greenland; (12) Kara.

